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United States Naval Postgraduate School

THESIS

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An Investigation of Data Transmission Through Media of Various Densities by Acoustic Means

by

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ABSTRACT

Ultrasonic transducers were used to couple the transmission of continuous-wave and pulse-modulated signals across relatively short paths of less than one meter through media of various densities. The experimental model used consisted of two concentric, cylindrical, stainless-steel tanks, one inside the other, with the area between them filled with either water or air. The investigation showed the feasibility of transmitting usable data to and from a unit which was isolated from a data source, i.e., from outside the outer tank to inside the inner tank, and vice versa, without physically penetrating the walls of either tank. An application hypothesis for a Submarine Launched Weapon System is presented as an example of employment of this technique since the weapon vehicle is relatively isolated from the fire-control system and since the elimination of cabling between the launcher and the weapon should enhance system performance.

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I. NATURE OF THE PROBLEM

This investigation was stimulated by the existence of acoustic devices that can detect flaws and measure wall thickness of material structures to which access is generally limited to one side. This suggested the possibility of transmitting control data or information by acoustic means through various media without physical penetration of the media and without imposing any additional operating limitations.

This investigation was undertaken to determine the feasibility of acoustically coupling the transmission of control data to and from units which are relatively isolated, i.e., surrounded or encased by a medium, or media, of perhaps varying density. The transmission of data to such units may neither be possible, practical, nor conducive to electromagnetic methods. Furthermore, cabling may not be desired or may impose limitations on the system because of cable penetrations which could affect its material structure. In addition, maintenance of other type devices may be restricted or require complete shutdown of the overall system operation. However, if the media can support acoustic wave propagation, then the coupling of the transmission by acoustic means may not only be feasible but may prove to be more practical and even more economical than other methods.

Analysis of empirical formulas and development of mathematical expressions contained in the literature [Ref. 4] and statistical data from other sources were considered and referenced. However, a feasibility study such as this investigation which used an experimental model was considered more apropos for this undertaking. In so doing the scope was narrowed to just the problem of the acoustic coupling of electrical signals through the media of this one model. Also, the particular type of transducer used may not have been the best suited to the task even though satisfactory results were obtained. Use of other supporting equipments and devices that would have made the model a complete working system were either postulated or simulated.

The experimental model consisted of two concentric, cylindrical, stainless-steel tanks, one inside the other, with the space between them filled with either air or tap water. Even though the inner tank was not a completely independent unit, it was postulated that the necessary devices and power supplies to make it so are available in the industry. The results of the experiment led to the conclusion that this technique could be satisfactorily applied to systems with configurations different from that of this model.

It was not intended to develop a generalized technique for design analysis and parameter selection that would best fit any system. This would be an ideal project for the

continuation of research in this area. The development of a mathematical model for use in a modern computer system would be an excellent example of such a project.

II. EXPERIMENTAL PROCEDURE

A. DESCRIPTION OF APPARATUS

A sketch of the experimental model and a schematic diagram of the overall setup are contained in Appendix A with actual photographs of the apparatus and its arrangement.

The outer tank was 153.0-cm long with an inside diameter of 32.2 cm. The inner tank was 61.0-cm long with an outside diameter of 26.8 cm. The radial difference or "gap" between the tanks was therefore 2.7 cm. The wall thickness of the stainless shell of both tanks was 0.6 cm. The outer tank was fitted with a drain-and-fill connection in the 1.0-cm thick circular plate that was welded in place to close that end. The opposite or open end had an outside flange for receiving a watertight closure plate. This closure plate was also 1.0-cm thick but had an 8.8-cm hole drilled through its center. This hole was fitted with a watertight phenolic ring with a 3.8-cm inner hole fitted with a neopreme rubber O-ring seal. The inside of the outer tank had neoprene-covered phenolic blocks that acted as spacers upon which the inner tank could be placed. In order to vent or pressurize the space between the two tanks, the outer tank had two air-hose fittings, one at each end and located at what was designated the top of the cylinder. The inner tank was closed at one end also with a welded circular plate 1.0-cm thick. The opposite or open end of the

inner tank had an inside flange for receiving a 1.0-cm thick watertight closure plate. This closure plate was penetrated by a watertight tube which was 33.0-cm long and 3.7-cm in diameter with a wall thickness of 0.1 cm. This tube protruded through the hole in the ring of the outer tank's closure plate. This allowed the cables connected to the transducers inside the inner tank to be passed through the tube and be connected to either the trasmitter or receiver equipments located in the laboratory. A neoprene-covered phenolic block was mounted to the top of the inner tank. This acted as a locking device as well as a guide. The inner tank could then be concentrically positioned and locked in place. Therefore, when it was installed, its longitudinal mid-point could be positioned 61.0 cm from the outer tank's open end.

The particular type of transducers used in this investigation had stainless-steel, threaded stud-like housings. Firm and watertight mounts for the transducer's housing were provided by welding stainless-steel nuts to selected positions on the outer and inner tanks. There were five such positions on each tank. Some of these had holes drilled through the walls of their respective tanks so that the face of the transducer could protrude into the space between the tanks. Three of the test positions for the outer tank were radially located on the cylindrical periphery 61.0 cm from the outer tank's open end. The remaining two positions were located in the end plates. One penetrated the welded

circular plate at the closed end and the other was on the outside skin of the closure plate for the open end; i.e., it did not penetrate the plate. The inner tank had similar fittings. Three of these positions were radially located inside the inner tank on its cylindrical periphery opposite those of the outer tank. Similarly, the two remaining test positions for the inner tank were located on the end plates. However, the penetration scheme was reversed. The one located on the open end's closure plate penetrated into the space between the tanks and the one on the closed end's welded plate did not penetrate. The penetration scheme for the radial positions provided flexibility also. There was only one position on the outer tank's wall that penetrated while two positions on the inner tank's wall were fitted for penetration. This permitted selection of different combinations of media through which the feasibility of the acoustic coupling could be tested and studied.

Since there were six transducers of this type available for the investigation, they were first used in the radial positions of each tank. The three transducers used in the outer tank's radial positions were denoted by the numbers 1, 2, and 3. The three transducers used in the inner tank's radial positions were denoted by the letters A, B, and C. Different modes of operation could then be designated by a number-letter or letter-number combination. A specific pair of transducers used in a test as well as the medium or media between their faces would then

correspond to a particular letter-number or number-letter combination. Appendix A contains a schematic diagram of the setup which shows a cross-sectional view of the model with these radial positions so denoted. The following table lists the designations of each transducer, its serial number, whether or not it penetrated the wall of its respective tank, its location in degrees relative to the top of its tank measured clockwise as viewed from the open end, and the media through which the acoustic coupling had to be made.

Outer Tank			Location	A.C.	Inner Tank		
Desig.	Ser.	Pen.	Deg. Rel.	Media*	Desig.	Ser.	Pen.
1	71	YES	090	W/A	A	72	YES
2	64	NO	000	S-W/A W/A-S	B	74	YES
3	73	NO	270	S-W/A-S	C	70	NO

The tests from the end plate locations were conducted after the tests from the radial locations. Since the serial number identifying each transducer was already associated with either a number or letter, the same correspondence was retained for the end-plate designations. However, in order to distinguish their use in these positions, a prime

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* W/A, water or air
S-W/A, steel to water or air
W/A-S, water or air to steel
S-W/A-S, steel to water or air to steel.

(') and a double prime (") indication was affixed to the number or letter associated with the transducer so used. The numbered transducers were again associated with outer tank positions and the lettered transducers were associated with inner tank positions. The prime sign indicated a position in the closed end's welded plate and the double prime sign indicated a position in the open end's closure plate.

The transducers used to convert the electrical signals to acoustic signals and vice versa had a ceramic sensing element of lead zirconate titanate. These sensing elements were radially polarized thin-wall ceramic cylinders operating in the radial and length mode utilizing the electrostrictive effect for the energy conversion process. The operating frequencies were in the ultrasonic range above 50 kHz. Experimental testing found the upper frequency cutoff to be about 350 kHz. All of the transducers were mounted face-on; i.e., the cylindrical axis of the sensing element was aligned to the direction desired for transmission or reception. Appendix A contains a specification sheet that lists the characteristics of each transducer and its dimensions.

The simulation of data transmission by continuous-wave signals was accomplished by using a sine-wave oscillator. The transducer selected for transmission was connected directly by coaxial cabling to this oscillator. For digital

data simulation, a pulse-modulated signal train was formed by using a plus-and minus square-wave generator with the sine-wave oscillator. A solid-state silicon diode was shunted across the output in order to short the negative-going pulse to ground. This formed a series of positive pulses which could simulate a serial train of binary "ones". The output was connected by coaxial cable to the transducer selected for transmission.

The electrical output of the transducer selected for reception of the acoustic signal coupling the gap was connected by coaxial cable to a rather special amplifier. This amplifier was designed for use with these transducers, and therefore its parameters were well suited to the application. These are listed below:

1. <u>High Input Impedance of 1000 MΩ shunted by 15 pF</u>

   The transducers had a nominal dc resistance of 10,000 MΩ and a capacitance of 4700 pF.

2. <u>Satisfactory Gain of +40 dB</u>

   The maximum output voltage into a rated load of 10 kΩ was 4 Vrms. A gain of +80 dB and an output voltage of 10 Vrms might have been better.

3. <u>Relatively Broad Frequency Response of 20 Hz to 100 kHz into a Rated Load of 10 kΩ</u>

   A flat frequency response for the range 50 kHz to 350 kHz would have suited this application better. However, the response was only down 4 dB at 300 kHz for this amplifier; i.e., the gain was +36 dB at 300 kHz.

4. <u>Low Output Impedance of 50Ω in Series with 2.2 μF</u>

This was a good match for the oscilloscope used for observing and recording the results.

5. <u>Low Noise Figure</u>

6. <u>Built-in Protection against Large Input Voltages</u>

7. <u>Built-in Protection for Shorted Outputs</u>

8. <u>A Power Supply Requirements of +28 Vdc with a Nominal Current Drain of 6 mA</u>

9. <u>Watertight, Corrosion-resistant, and Compact Packaging -- 5 Inches in Length and 7/8 Inch in Diameter</u>

The output of the amplifier was connected by coaxial cable to a dual-beam oscilloscope. This type of scope was selected so that the transmitted and received signals could be simultaneously observed and compared. It also permitted an attached oscilloscope camera to photograph the oscilloscope traces together. The inherent high-Q of the transducers required fine tuning of the oscillator used in the transmitting scheme. The dual-beam oscilloscope was used to observe the maximum response while the oscillator was tuned. The maximum response was defined as the maximum ratio of the received signal voltage to the transmitted signal voltage determined from their respective traces on the dual-beam oscilloscope. This criteria may not have been the optimum since neither the shape of the pulse nor the phase of the wave of the received signal with respect to the trasmitted signal was considered.

Waterproof shielded coaxial cable and its associated connectors, adapters, and fittings were used exclusively. A rather simple high-pass filter was placed in the circuit just ahead of the amplifier to successfully demonstrate the reduction of the effect of noise.

B. TESTS

For both the continuous-wave and pulse-modulated signals a zero to +1.0-V peak voltage, denoted Vpi, was applied to the input of the transducer selected for transmission. An acceptable frequency for transmission was determined by carefully tuning the sine-wave oscillator through the frequency range of 50 kHz to 350 kHz. The oscillator was considered tuned when the ratio of the received signal trace to the transmitted signal trace was observed to be at its maximum on the dual-beam oscilloscope.

For pulse-modulated signals several different combinations of pulse repetition rates (PRR) and pulse durations (PD) were tried. The final combination, arbitrarily chosen, was 250 pps and 2 ms, respectively. This was found to be an acceptable combination for the media and devices involved in this investigation.

The first two tests conducted had a pair of transducers clamped together, face to face, separated with a 0.15-cm piece of rho-c rubber. This was done to determine the attenuation attributed to just a transmitting-and-receiving pair of transducers without considering the medium between them. The tests included both the continuous-wave case and the pulse-modulated case.

The next six tests conducted were for determining the acceptability and the amount of attenuation associated with the radially located transducer pairs directly opposite one another. Continuous-wave signals were used and the space between the tanks was filled with either air or tap water. (Note: Since the results were very similar for transmissions from the inner-tank transducers to the ones on the outer tank, they were not included in the data and photographic results contained in Appendix B.)

The remaining tests were conducted for pulse-modulated signals. The first four tests of this series were for the pair of transducers denoted 1-A that penetrated the walls of their respective tanks. This pair directly faced each other across the medium of the gap. For comparison of results, the amplifier was bypassed for two of these tests. The next four tests conducted were with the remaining two pairs of transducers denoted 2-B (or B-2) and 3-C (or C-3) that also faced each other. This was to investigate the acoustic coupling through the media of steel-water, water-steel, and steel-water-steel. The results of special tests were included to show the effect of a change in frequency on the shape of the received pulse. The final three tests of this series were conducted with the space between the tanks filled with only air. It was from this series of tests that the feasibility of acoustically coupling data was determined.

The next series of tests was conducted to investigate the amount of attenuation between different combinations of transducers other than those facing one another. This was to determine possible interference problems if more than one pair of transducers were used in the same system; e.g., one pair for a forward loop or data input and another pair for a feedback loop or data output.

The final series of tests was conducted to investigate the relative security of transmissions from the radially located transducers with respect to the media between test transducers located in the end plates. In addition, possible interference problems from external sources could be simulated by transmitting from the test positions located in the end plates of the outer tank.

III. PRESENTING OF THE DATA

Dual-beam oscilloscope photographs were taken of the traces of the transmitted electrical signals and the traces of the received electrical signals for each of the tests. The data and photographic results are contained in Appendix B.

Attenuation was defined for this investigation as the ratio of the received or output voltage (denoted Vpo) to the transmitted or input voltage (denoted Vpi) expressed in decibels, less the gain of the amplifier expressed in decibels.

$$\mathrm{Attn(dB)} = 20\log_{10}[\mathrm{Vpo/Vpi}]\ \mathrm{(dB)} - \mathrm{Ampl(dB)}$$

The voltage ratio was determined from dual-beam oscilloscope observations. The gain of the amplifier was determined from a frequency response test.

Tests 1 and 2 showed a -6 dB and -10 dB signal attenuation for the continuous-wave case and the pulse-modulated case, respectively. These tests were conducted with the transducers clamped together face to face.

The next series of tests had the transducers directly facing one another across the media of their respective gaps. The results showed various degrees of attenuation and wave shapes. The values of attenuation ranged from -26

dB for the continuous-wave signals through just a water path to -80 dB for the pulse-modulated signals through a steel-air-steel path.

The final series of tests was primarily concerned with determining mutual interference problems as well as relative security and interference from externally simulated sources. The results showed a range of values for attenuation from -38 dB for a water path to -67 dB for a steel-water-steel path. Tests with the space between the tanks filled only with air were difficult to analyze because the amount of attenuation was greater than 80 dB.

Time delays between the transmitted and received signals appeared to be readily apparent and easily determined from the traces on the dual-beam oscilloscope. The relative phase of a received continuous-wave signal or the shape, and positions, of a received pulse-modulated signal with respect to the transmitted signal were very dependent upon the transmitted frequency. Because of these variations with frequency, time delays were not determined. However, time delays are surmised to be relatively short and should not be a significant problem in employing this technique.

IV. CONCLUSIONS

A. DISCUSSION OF RESULTS

It is concluded that it is feasible to ultrasonically transmit control data or information through various media to relatively isolated units. The media involved must possess the properties necessary to support the propagation of an acoustic wave, and be of reasonable dimension. It is further concluded that applicable systems can be practically and economically adapted and converted to employ this technique.

The shape and orientation of the received pulse-modulated signals were observed to be both positive and negative pulses centered about a zero or ground reference. However, the transmitted signals were positive pulses since the shunted diode was shorting the negative-going portions to ground. The received wave shape was attributed to the inherent properties of acoustic wave propagation and transducer action. The conversion of electrical signal energy to acoustic signal energy, and vice versa, was by the electrostrictive effect of the ceramic sensing element in each transducer. The propagation of an acoustic wave through the media involved required particle motion in those media. The inertia of the particles and the elasticity of the media caused their respective particles to sequentially oscillate around their normal positions and perhaps even

the execution of an orbit around that position [Ref. 1]. This can be said to produce a positive-and-negative-going pressure front with respect to the static pressure of the media involved. As this pressure front progressed through the media the acoustic wave was thereby propagated. When this acoustic wave impinged upon the face of the receiving transducer, a deformation of the sensing element resulted and an electrical signal was produced that was linearly proportional to the strain [Ref. 2]. If it had been desired, an additional diode could have been shunted across the output of the receiver so that it would have shorted the negative-going portions of the electrical signal to ground.

The sensing element of these transducers had a relatively high capacitance with a distinct and finite rise time (7 μs). The pulse duration (PD) of the pulse-modulated signals had to be of sufficient length to allow time for the conversion process to satisfactorily take place. The pulse repetition rate (PRR) was adjusted accordingly so that the sensing element could recover before the next impinging wave. The PRR and PD selected for this investigation were considered satisfactory for this purpose in that usable replicas of the transmitted signals were received.

It was determined from these results that it is feasible to use a pulse-modulated signal. However, it would require the proper utilization of associated filters, discriminators, threshold detectors, digital storage registers,

samplers, multiplexers, D/A and A/D converters, amplifiers, local oscillators, modulators and demodulators, power supplies, and such, to be a complete and usable sub-system. However, it is considered that an amplitude-modulated continuous-wave signal may be better suited for applications envisioned for this technique. Signal processing and coding schemes for this and various other types of signals are contained in the literature [Ref. 3]. The associated devices required are considered within the present state of the art or available in the industry.

The transducers used in this investigation were rather arbitrarily chosen because of their availability to this investigator. In that regard they were not necessarily the optimum type or best configuration for this application. Perhaps a thin ceramic disc would have been better suited. For example, a thin ceramic disc of barium titanate with a thickness of 0.2 cm and a radiating area of 10.0 cm^2 was operated in the thickness mode. This produced 19.5 W of acoustic power when 10 Vrms at 1.44 MHz was applied [Ref. 2]. This example indicated that the selection of a particular type of transducer could be an important factor in adapting this technique to a specific application.

The receiving circuitry could have been improved by using a bandpass filter and a +80-dB amplifier to provide a flat frequency response in the range from 50 kHz to 350 kHz.

The problems of noise, interference, and interaction must always be taken into account but are considered design problems that can be solved by using well known techniques and available devices. Transmission security and interference from external sources are considered within acceptable limits for almost all cases of employment envisioned for this technique.

Transducers of this type are rugged and durable, and, in this case, capable of withstanding shock pressure as great as 200 psi and operating temperatures from -40° to $+225^{\circ}F$. The associated circuitry and devices mentioned above could be of solid-state design to enhance their compactness and ruggedness and to minimize power requirements.

It is further postulated that power could be similarly coupled through the media. This power could be stored, could minimize the drain from a battery, or could be directly used to operate devices.

In control system applications, multiplexers could be simplified by employing an additional pair of transducers to close the feedback loop. Therefore, a complete subsystem could employ three pairs of transducers with each pair operating at a different frequency. For instance, one pair could be used for data input, another pair for data output, and a third pair for supplying power. The reliability of such a system should be very acceptable for most applications. When considering the additional feature of neither

requiring physical penetrations nor cables through the media involved, this technique would be rather unique and should be considered well suited to the job.

As mentioned before, the continuation of research in this area could be in the form of developing a computer-orientated mathematical model. Such a model could be programmed to allow variation of the input parameters necessary for the design analysis of a specific system desired for adaptation to this technique. Further information concerning the development of such a model is in the literature [Ref. 4]. In addition, a detailed analysis and tabulation of the characteristics of various media and applicable devices would be required.

B. AN EXAMPLE OF APPLICABILITY

In order to show the possible usefulness for employing an acoustic coupling such as used in this investigation, an example of applicability will be presented. A Submarine Launched Weapon System will be considered as one such system that could benefit from the employment of this technique. The weapon vehicle in its launcher can be considered relatively isolated from the system that controls it; e.g., a torpedo, the associated torpedo tube, and the Torpedo Fire Control System, abbreviated TFCS for later reference. The uniqueness of the coupling feature is considered significant in this case since neither hull penetrations nor torpedo control cables would be required.

Neither the hypothesis that follows nor this investigation were intended as an alteration proposal. They were not intended as a modification request, a design change recommendation, or a complete research report. This investigation was merely a feasibility study of an acoustic coupling technique using an experimental model. The hypothesis that follows is just an example of employment of this technique. However, it is suggested that further research into this area should be considered as a worthwhile project. Some other examples of possible application will only be mentioned. Data transmissions between control devices or instrumentation inside a nuclear reactor and its associated control stations, and transmission of control signals to units outside the main pressure hull of submarines, rescue vehicles, or hydrographic research vessels designed to operate at deep depths, are two such examples.

Since this technique would neither involve hull nor launcher penetrations, the watertight integrity of the submarine would be enhanced. It would also eliminate the penetration of the torpedo by the control cable, which carries external power and control data from the TFCS to the torpedo. Peripheral devices associated with the use of this cable could also be eliminated. This would probably be welcomed by submariners and should enhance system performance. The time required to load a torpedo into a tube and ready it for use could be reduced. The possibility of an erroneous or faulty cable connection would no longer

exist, e.g., inadvertent motor starts, flooded cables, bent pins, open leads, etc. The possibility of torpedo tube down-time resulting from a cut cable damaging the seats or gaskets of a slide valve or drain valve would be eliminated. Furthermore, if submarines of the future and their associated weapons were designed for weapon launchers mounted outside the main pressure hull, it is envisioned that an acoustic coupling technique or a similar method which would not require hull penetrations would be employed.

So that security classification requirements are not violated, all assumptions and postulations that follow are strictly theoretical for the purpose of presenting this example.

One of the first aspects that should be considered is the compatibility of the data rate that can be processed to that required for successful implementation. Of all the control data to be transmitted to a torpedo, the torpedo gyro-angle order normally changes continuously and at a faster rate than the other data. Consider a theoretical target at its closest point of approach to be at a range of 1000 yards with a relative speed across the line of sight of 30 knots. The maximum rate of change of the bearing to the target would be about 60 deg/min or 1 deg/sec. Assume that the torpedo gyro-angle order would be stored in digital register awaiting conversion to an analog signal that would actually be used to make the setting just prior to

launch. If increments of 0.5 deg were to be transmitted, then the rate of change that could be expected would be two increments per second.

In order to simplify the coding scheme for this example, assume that the output of the TFCS could be converted to or transmitted as a digital pulse train of serialized information. One control word would then be composed of several different commands or settings. For instance, fifteen different commands or settings can be assumed to require a total of 60 bits or pulses per control word. The control word would then contain all the information required to control the torpedo. The proper reception of this control word by the torpedo could be verified by the TFCS in a feedback loop. The values of the registers in the torpedo could be sampled and returned to give matched indications on the TFCS console. In addition, the actual settings of the control devices could be checked just prior to launch to give similar indications of proper torpedo response.

Assume that a PRR and PD of 250 pps and 2 ms respectively would satisfy these theoretical requirements. The digital pulse train carrying the control word could be used to trigger an oscillator whose frequency had been preset to correspond to that best suited for the acoustic coupling. The received signals could then be processed by a special unit inside the torpedo designed for this purpose. This unit would have to contain all the components and devices

necessary to completely process all commands and settings so received. For ease of reference, this unit will be abbreviated, WCP, meaning Weapon Command Processor.

For wire-guided torpedoes an additional unit similar to the WCP could be placed inside the tube with the guidance wire housing. This unit would receive signals from the TFCS and relay them through the guidance wire to the WCP and vice versa. Again, for ease of reference, this unit will be abbreviated, LRU, meaning Launcher Relay Unit. The LRU could be located in a housing that could also contain an external spool of torpedo guidance wire. This housing could be permanently mounted to the inside of the breech door since all cabling would have been eliminated from that location. A special connector could be designed that would permit quick-connect and quick-disconnect of the wire in the spool to the LRU. The other end of the wire in this spool could have been previously connected to its torpedo while it was stored in the room. The torpedo could then be loaded and locked in its tube, the external spool placed in the housing, and the breech door shut and in so doing tube loading would be completed.

The acoustic coupling would be between the LRU and another somewhat similar unit located on the oustide periphery of the tube near the breech end. This unit will be abbreviated, SCP, meaning System Command Processor. This unit would have to have the additional task of routing the launch command to the tube firing mechanisms. The acoustic

coupling frequencies for data input and feedback data output could be initially set during installation of the SCP and LRU. Periodic maintenance tests could be scheduled to check their proper operation. Special codes and discriminating circuits could be used for critical commands such as: "PRIME" (or warm-up), "ABORT" (or shutdown), "FIRE" (or launch), "TEST" (or training), etc. This would greatly lower or eliminate the possibility of inadvertent actions or spurious signals causing unwanted operation.

Special portable test equipment could also be designed that would allow torpedo checkout and system testing. Provisions could be made so that during these tests external power could be supplied either to charge power packs or to minimize their use.

The WCP would have an internal power supply. Perhaps it could be designed for float-charging from external power supplied through an acoustic coupling technique. Relay of this amount of power through the LRU would not be practical because of the guidance-wire limitations. However, the SCP could be fitted with an additional transducer in order to couple this power to a transducer in the WCP, designed with associated circuitry for this purpose. In addition, the LRU could be supplied power in a similar manner for its own requirements. In order to reduce the power supply requirements of the WCP inside the torpedo, the torpedo's main propulsion battery could be activated just

prior to launch, e.g., one to five minutes prior to launch in order to warm-up and position those control devices requiring such action.

The following is a theoretical sequence of events which also summarizes the example:

1. All pre-launch preparations previously completed.

2. Weapon employment required and denoted.

a. Torpedo tube flooded and equalized with sea.

b. Wire guidance selected at the TFCS.

c. Water selected at the SCP. (Note: This implies the medium between the inside of the breech door and the outside housing of the LRU will be water. No penetration is required.)

3. TFCS has a solution, control data is ready, and a particular torpedo is assigned.

a. Control data is digitally read-in and read-out every 0.5 seconds.

b. The torpedo tube is made fully ready. (Note: This includes opening of the muzzle door.)

4. Permission is obtained to prepare the torpedo for launch.

a. "PRIME" activates the torpedo's main propulsion battery and checks its voltage within operating limits.

b. Warm-up of control devices commences.

c. D/A conversion is made to set all control devices that require such settings. (Note: A/D conversion is also required for feedback of such settings for verification.)

d. All settings and commands are verified and following.

5. Standby to launch.

a. Final check of the TFCS solution is considered satisfactory.

b. All indications are matched and the system is ready to launch.

6. "FIRE".

a. Tube firing mechanisms are activated.

b. Torpedo's main propulsion motor is started.

c. Tube exit and the torpedo is running normally.

7. Post-launch guidance commences. (Note: Since all pre-launch commands and settings have used the guidance wire, there is no difference in the post-launch phase except perhaps the restriction of certain commands or the facility of the torpedo to continue with the last information received if the wire is cut -- and of course the wire is getting longer.)

As stated before, this was presented as just an example, using theoretical assumptions and parameters for relating the system to this technique. It was not meant to imply that the present system was not satisfactorily performing; but perhaps this technique should be considered for further research. The reduction of hull penetrations in submarines is considered pertinent to submarine safety.

C. CLOSING SUMMARY

It is considered that this investigation, using an experimental model, has determined the feasibility of coupling data ultrasonically to and from units which are relatively isolated. This acoustic coupling technique would neither require physical penetration of the structure nor cabling through the respective media of the system being adapted for its use. However, the intricacies of the structural design and the configuration of the various media involved could restrict the employment of this technique. The number of acoustic boundaries, the thickness of the solids, and the length of the transmission path could impose difficult problems. Perhaps some of these problems, including scattering and absorption, could be solved by having a series of acoustic relay units, but this may not be practical. The thickness of the solids could be of such magnitude to preclude the use of present day ultrasonic devices, even those designed for high-power applications.

It is hoped that the continuation of research for development of this technique will be motivated by this investigation. In closing, the following points are summarized:

1. Acoustic coupling of information through short paths of various media such as steel, water, air, and combinations thereof is feasible within reasonable limits.

2. Because of the wide range of transducer elements and configurations available, it is considered that desired data rates can be obtained for many applications.

3. Time delays should not be a significant problem.

4. The effects of noise, interference, interaction, reflection, reverberation, and multi-paths can either be reduced or eliminated by either design or employment of devices for that purpose.

5. The ultrasonic frequency range is conducive to the employment of this technique.

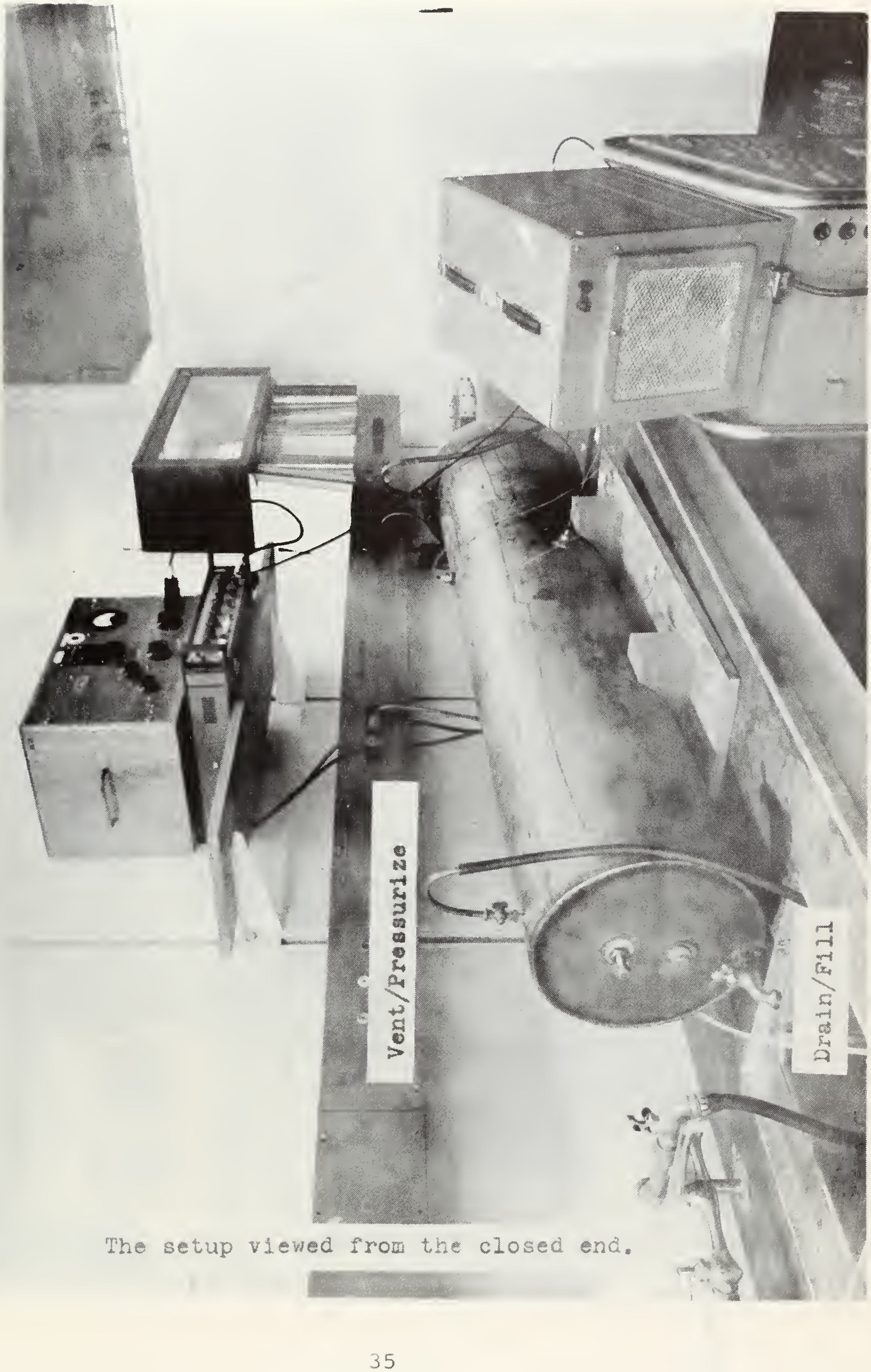
6. Self-contained power requirements are reasonable considering that solid-state design can be utilized.

7. The Submarine Launched Weapon System was presented just as a theoretical example of applicability for employing this technique.

8. The cost of development and implementation of this technique is considered commensurate with the gain in operational performance and maintenance requirements.

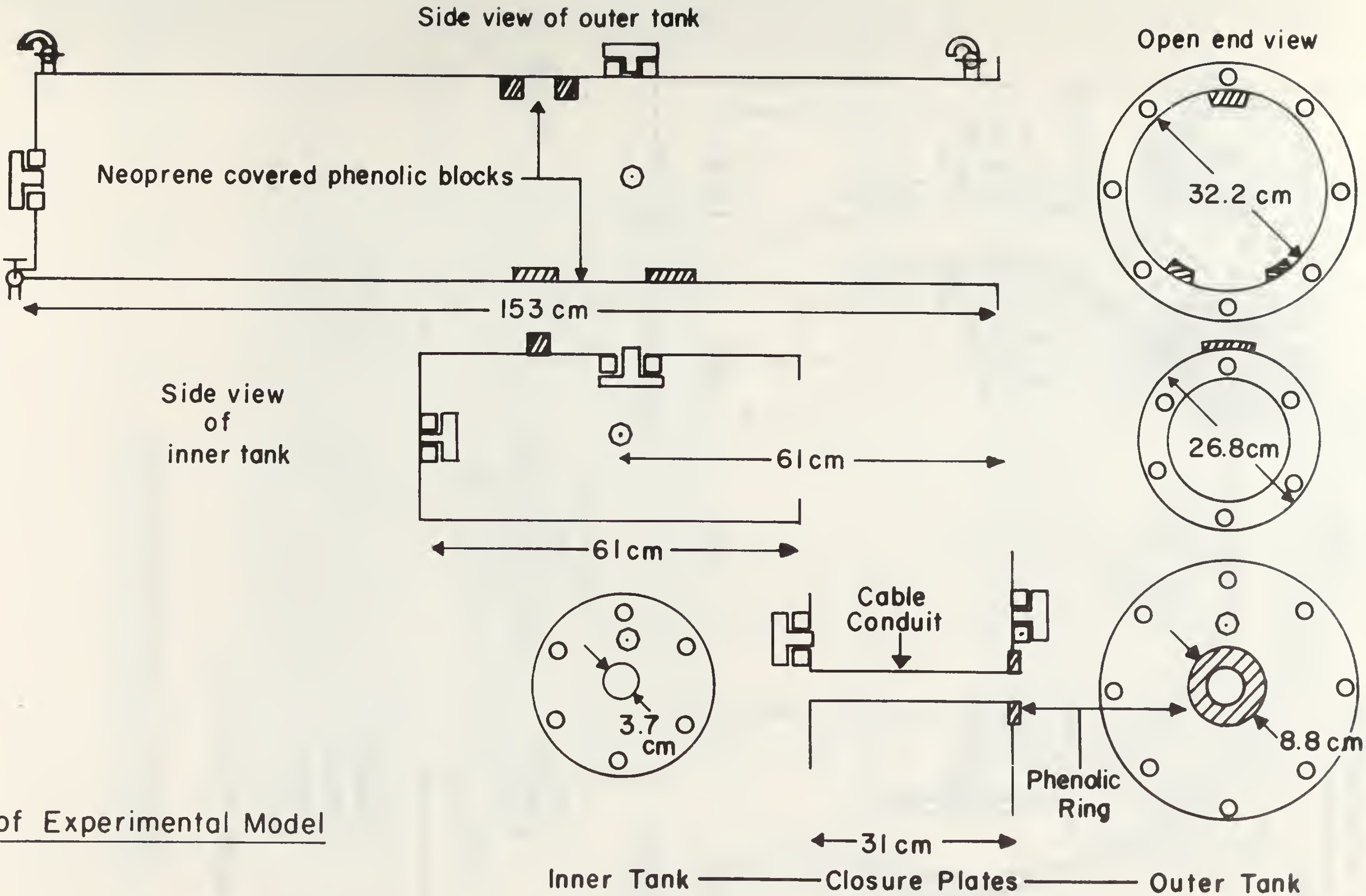
APPENDIX A. THE APPARATUS AND THE SETUP

The setup viewed from the open end.

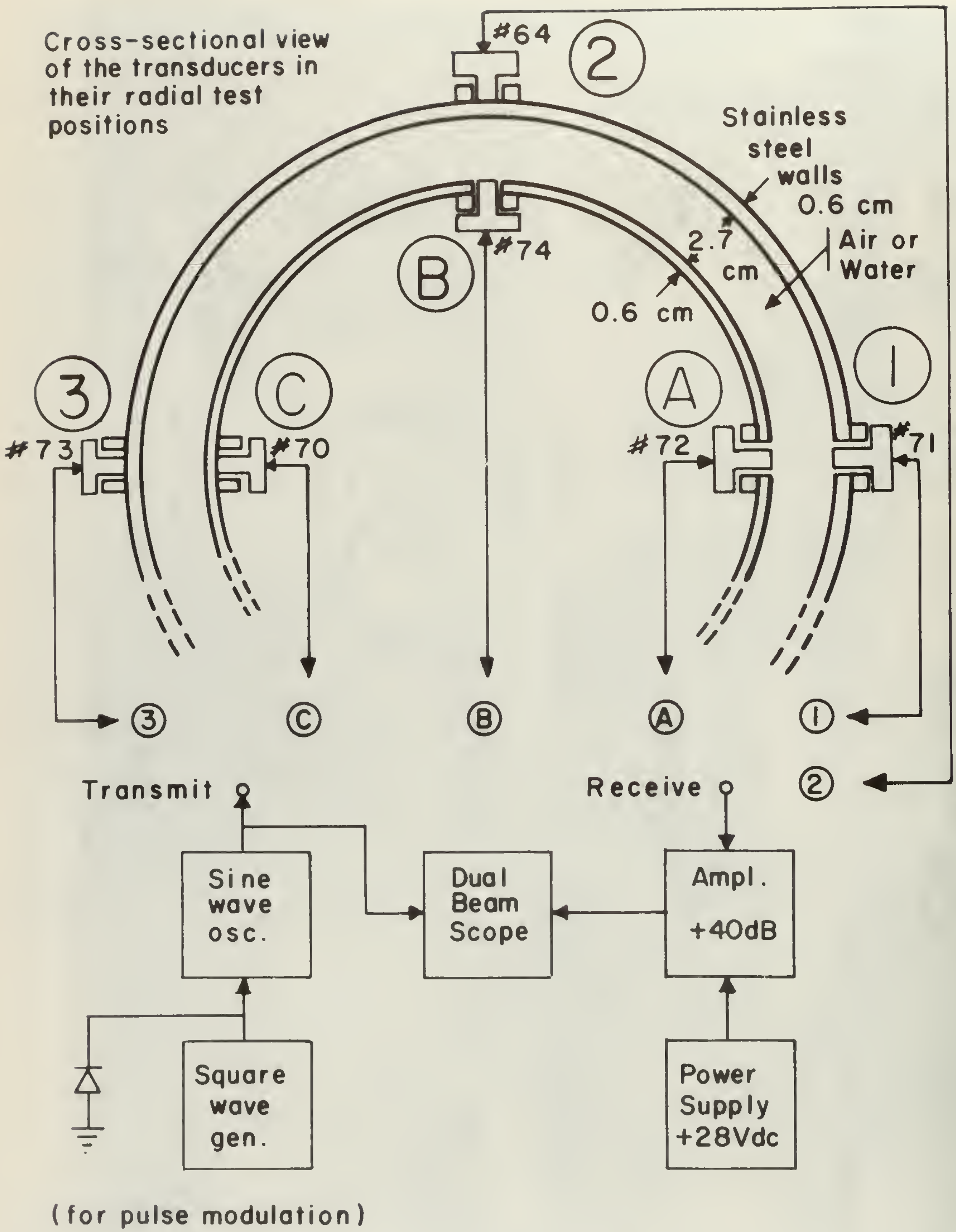


The setup viewed from the closed end.

Breakdown view of the model



Sketch of Experimental Model

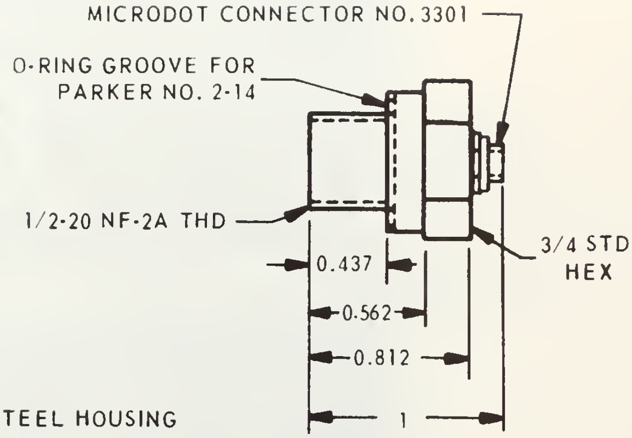


Schematic diagram of the setup

Transducer Specifications:

TRANSDUCER

STAINLESS STEEL HOUSING



TRANSDUCER

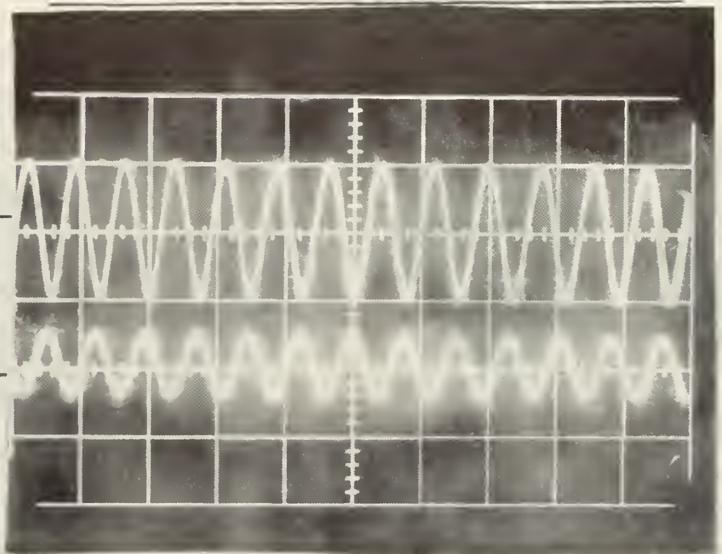
Transducers (1) Desig.	Ser.No.	Cap. (2) pF	Average Sensitivity (3) pC/psi	V/psi	dB
1	71	4730	890	0.189	-111
2	64	4670	650	0.139	-114
3	73	4860	1110	0.228	-110
A	72	4630	822	0.178	-112
B	74	4510	1020	0.227	-110
C	70	4540	1140	0.250	-109

Notes: (1) The transducers were radially polarized thin-wall ceramic cylinders of lead zirconate titanate.

(2) The dc input resistance was 10,000 megohms and the leakage resistance from the transducer's housing to its output terminal was negligible.

(3) Sensitivity calibration data was furnished with the transducers by the manufacturer. The charge sensitivity was measured in pico-coulombs (pC) per unit pressure in pounds per square inch (psi). The voltage sensitivity was measured in volts per unit pressure (V/psi) for an open reference to one volt per dyne per square centimeter.

APPENDIX B. THE DATA AND PHOTOGRAPHIC RESULTS



XMT: 3

RCV: 2

1.0 V

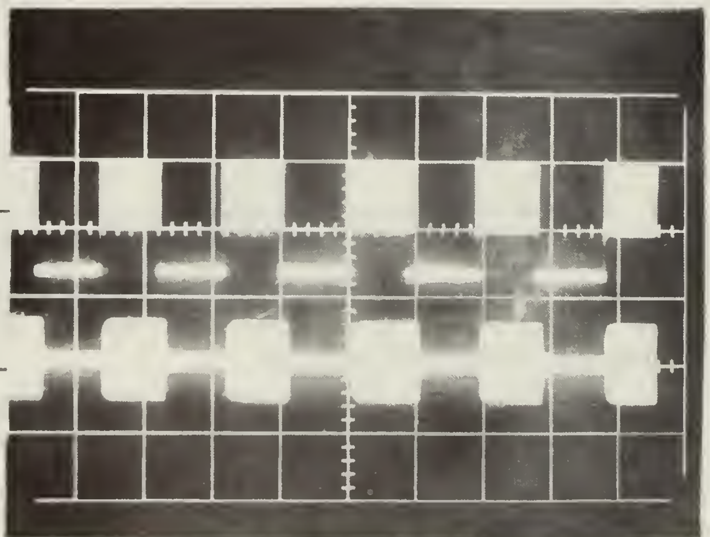
Test No. 1

1.0 V

$5 \mu s$

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
3	2		CW @ 1.0		250	0.500	-6	0	-6

Media: Clamped together face on.



XMT: 3

RCV: 2

1.0 V

Test No. 2

0.5 V

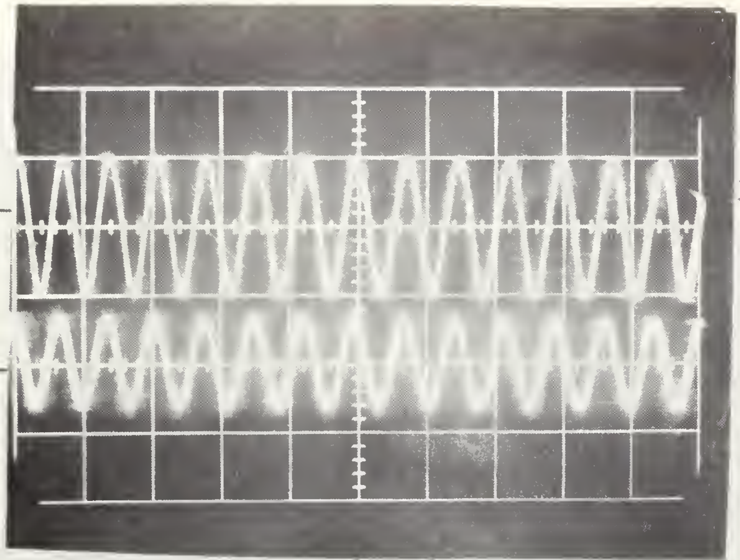
2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
3	2		CW @ 1.0		250	0.300	-10	0	-10

Media: Clamped together face on.

XMT: 1

RCV: A



1.0 V

Test No. 3

5.0 V

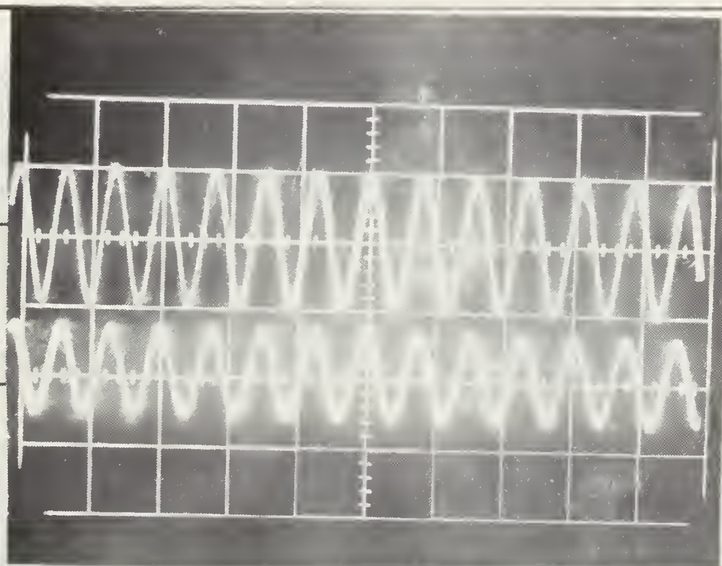
5 µs

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
1	A	CW @	1.0		262	3.500	+11	+37	-26

Media: Water

XMT: 1

RCV: A



1.0 V

Test No. 4

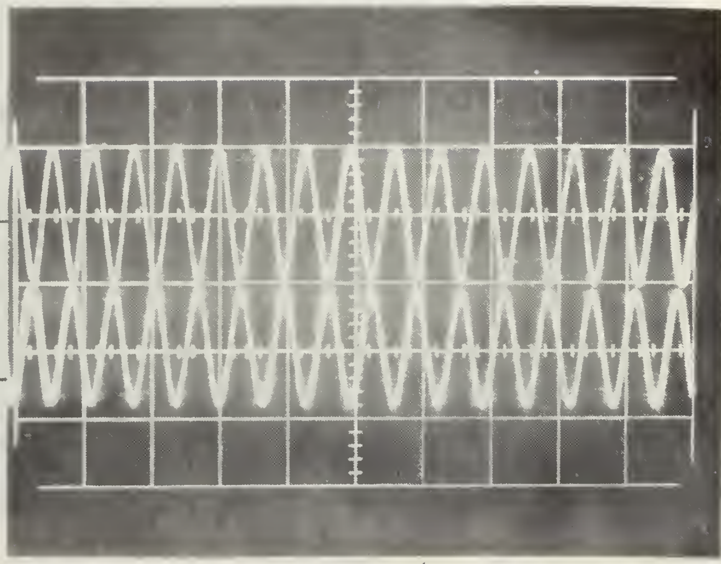
0.1 V

20µs

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
1	A	CW @	1.0		66	0.071	-23	+40	-63

Media: Air

XMT: 2



1.0 V

Test No. 5

RCV: B

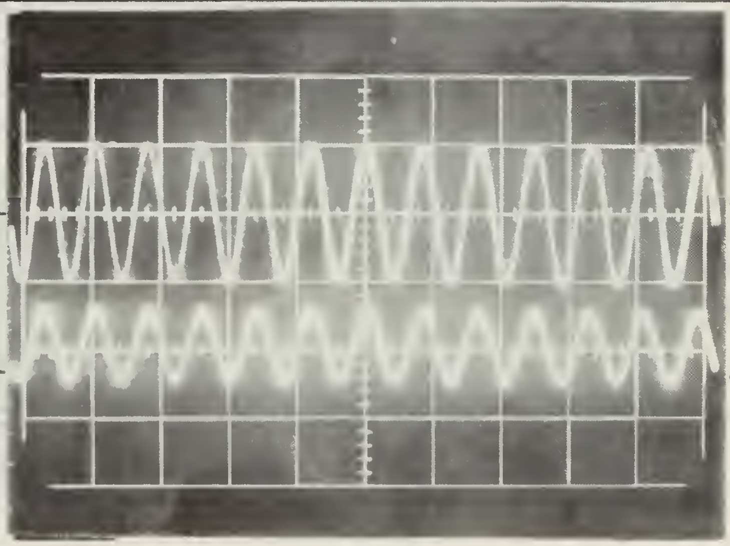
0.5 V

5 µs

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
2	B	CW @	1.0		300	0.450	-7	+36	-43

Media: Steel - Water

XMT: 2



1.0 V

Test No. 6

RCV: B

0.1 V

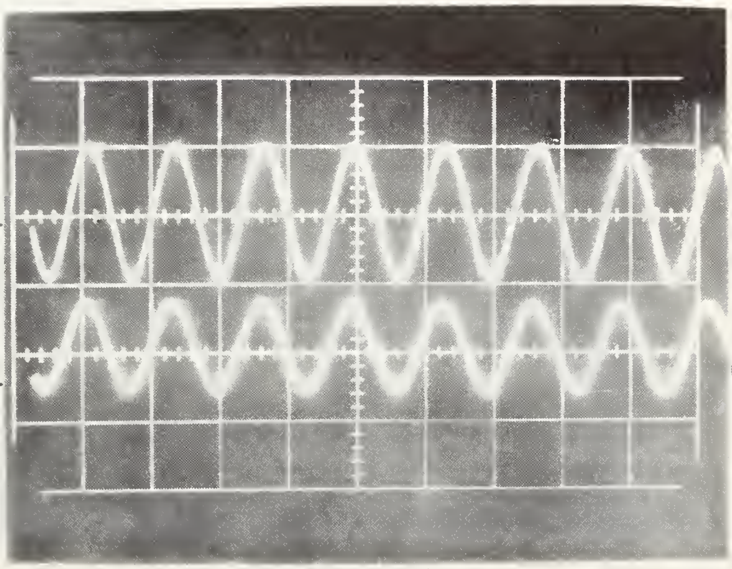
20 µs

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
2	B	CW @	1.0		61	0.057	-25	+40	-65

Media: Steel - Air

XMT: 3

1.0 V



Test No. 7

RCV: C

0.2 V

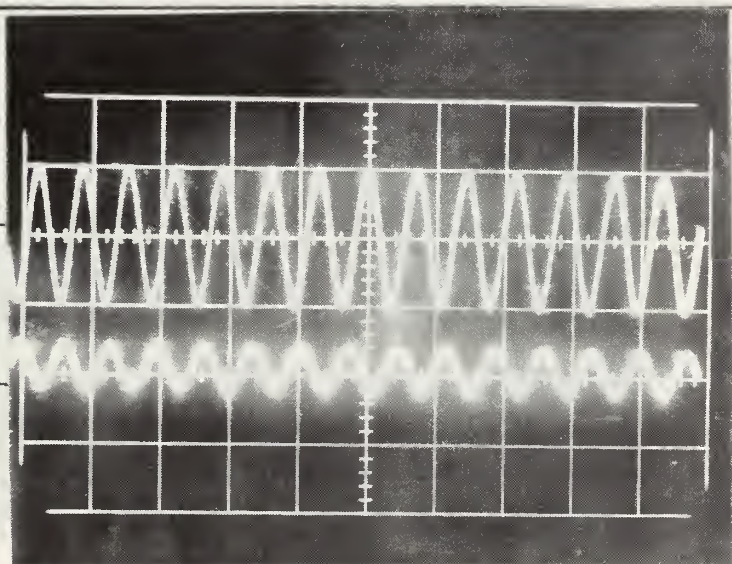
10 µs

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
3	C	CW @	1.0		76	0.141	-17	+40	-57

Media: Steel - Water - Steel

XMT: 3

1.0 V



Test No. 8

RCV: C

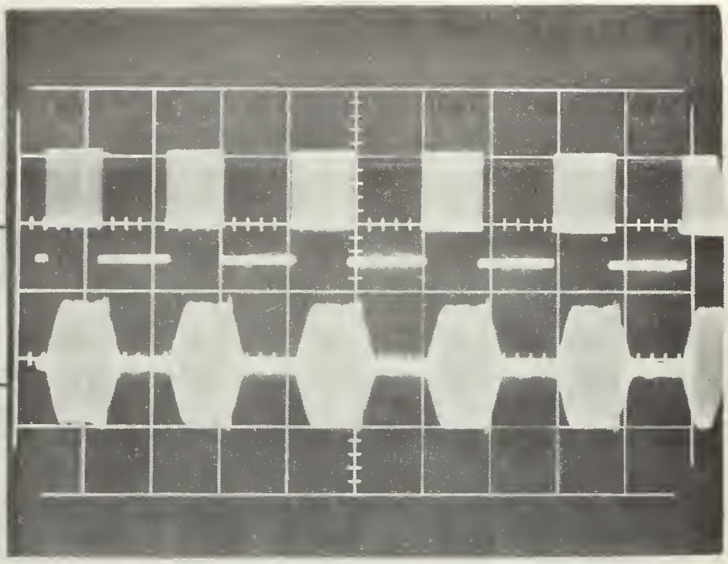
0.05 V

20 µs

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
3	C	CW @	1.0		70	0.020	-34	+40	-74

Media: Steel - Air - Steel

XMT: 1



RCV: A

1.0 V

Test No. 9

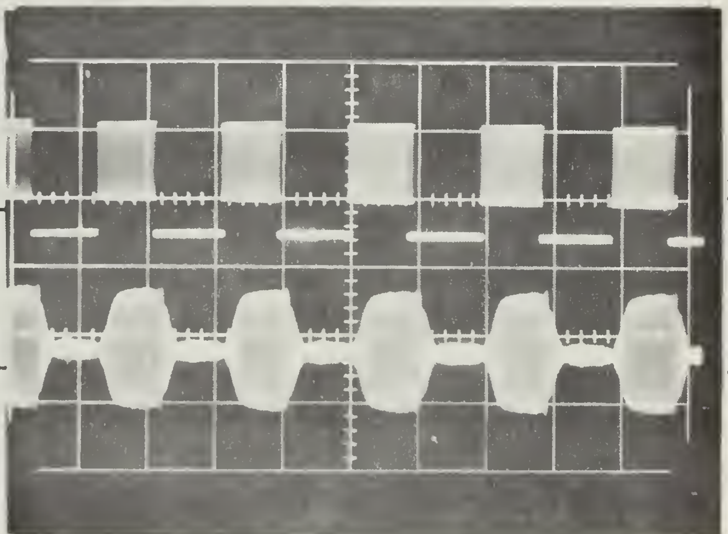
2.0 V

2.0 ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
1	A	250	2	1.0	265	1.750	+5	+37	-32

Media: Water

XMT: A



RCV: 1

1.0 V

Test No. 10

2.0 V

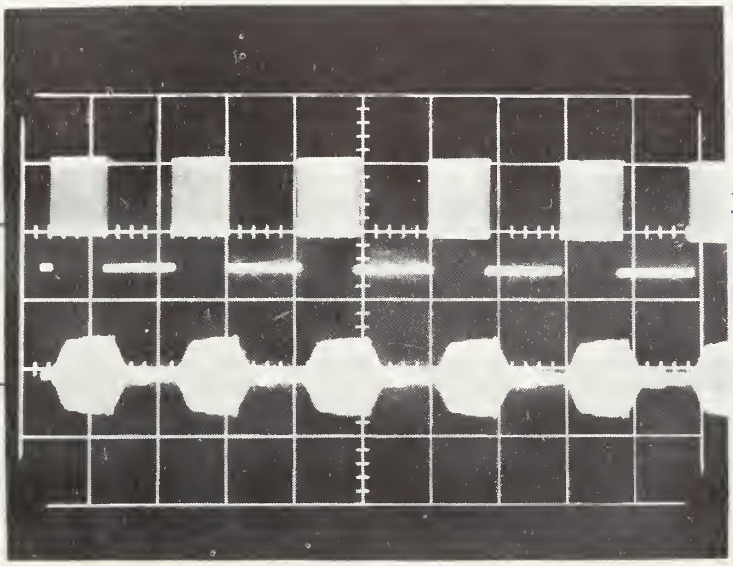
2.0 ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
A	1	250	2	1.0	265	1.750	+5	+37	-32

Media: Water

XMT: 1

RCV: A



1.0 V

Test No. 11

0.05 V

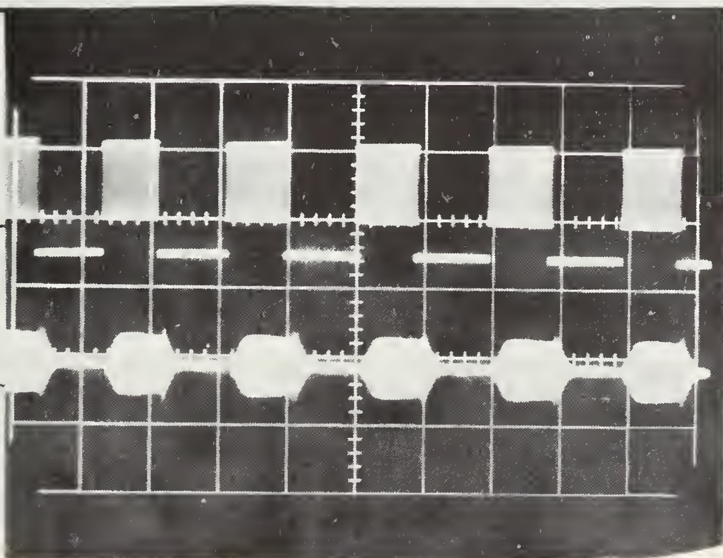
2.0 ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
1	A	250	2	1.0	265	0.028	-31	0	-31

Media: Water

XMT: A

RCV: 1



1.0 V

Test No. 12

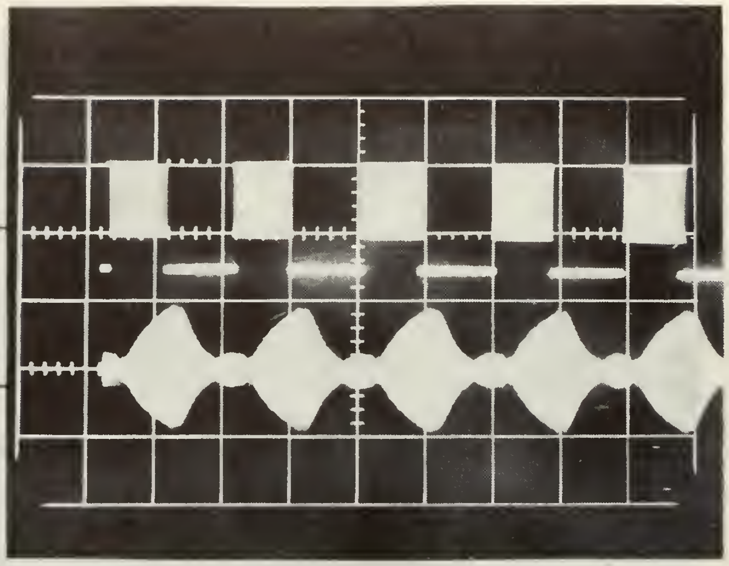
0.05 V

2.0 ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
A	1	250	2	1.0	265	0.025	-32	0	-32

Media: Water

XMT: 2



1.0 V

Test No. 13

RCV: B

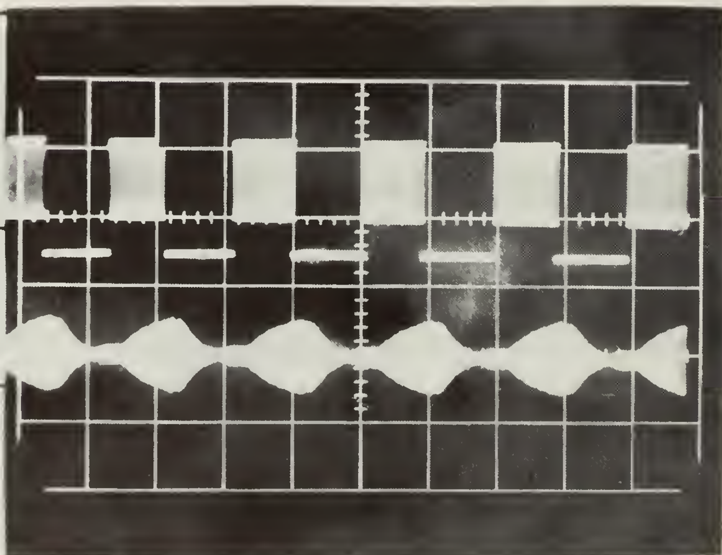
0.5 V

2.0 ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
2	B	250	2	1.0	300	0.500	-6	+36	-42

Media: Steel - Water

XMT: B



1.0 V

Test No. 14

RCV: 2

0.5 V

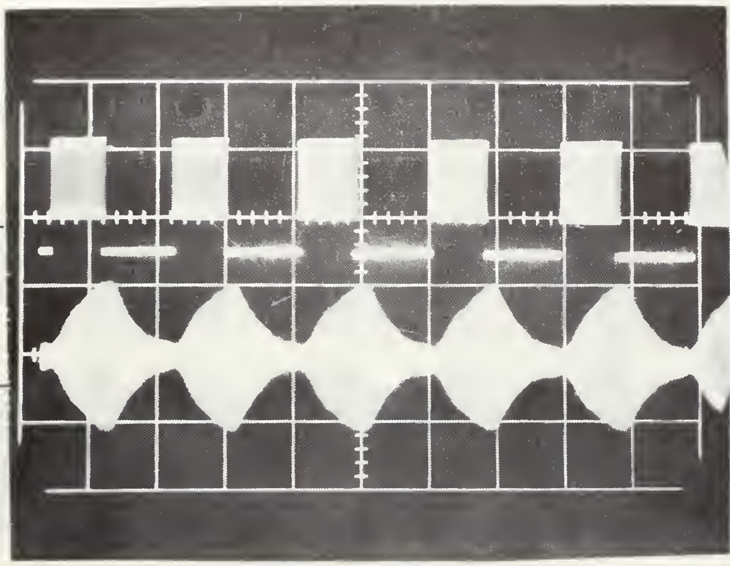
2.0 ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
B	2	250	2	1.0	300	0.250	-12	+36	-48

Media: Water - Steel

XMT: 3

RCV: C



1.0 V

Test No. 15

0.2 V

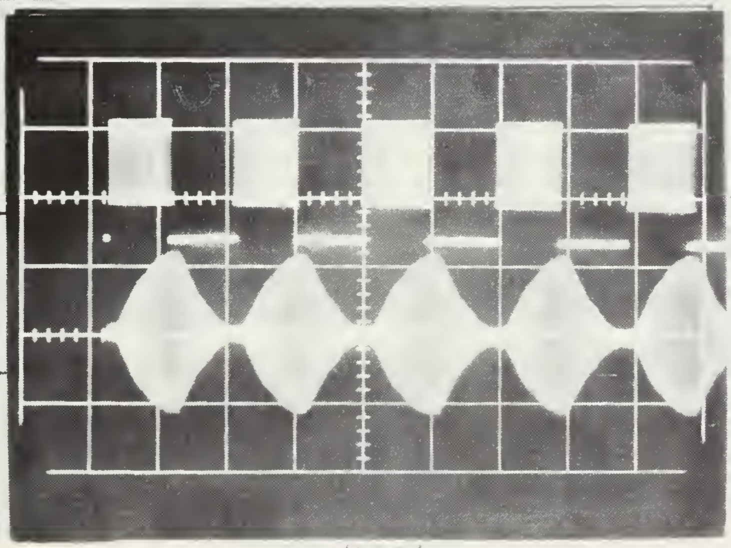
2.0 ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
3	C	250	2	1.0	75	0.200	-14	+40	-54

Media: Steel - Water - Steel

XMT: C

RCV: 3



1.0 V

Test No. 16

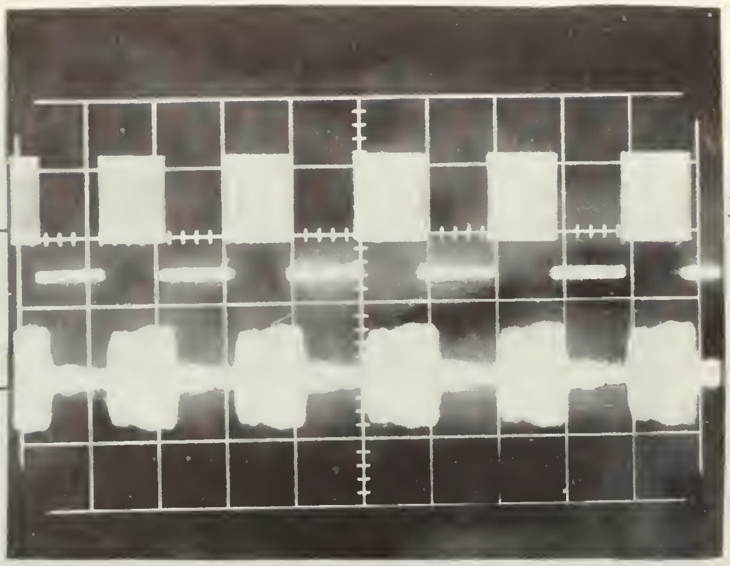
0.2 V

2.0 ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
C	3	250	2	1.0	75	0.225	-13	+40	-53

Media: Steel - Water - Steel

XMT: 3



1.0 V

Test No. 17

RCV: C

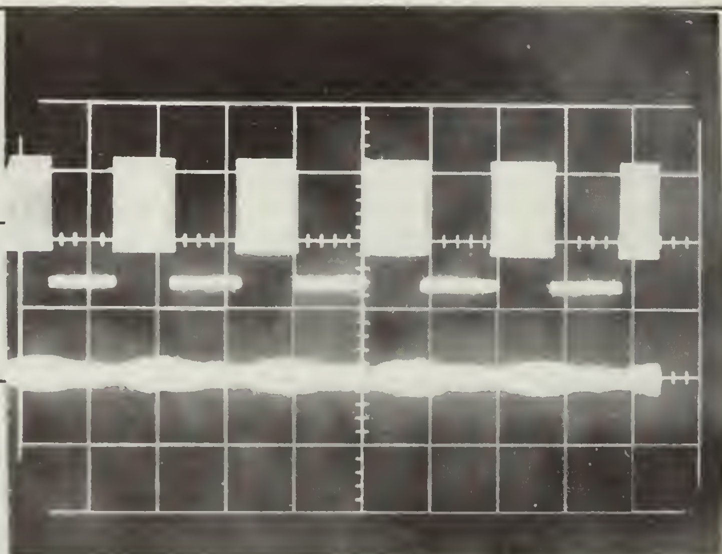
0.1 V

2.0 ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
3	C	250	2	1.0	265	0.064	-24	+37	-61

Media: Steel - Water - Steel

XMT: 3



1.0 V

Test No. 18

RCV: C

0.05 V

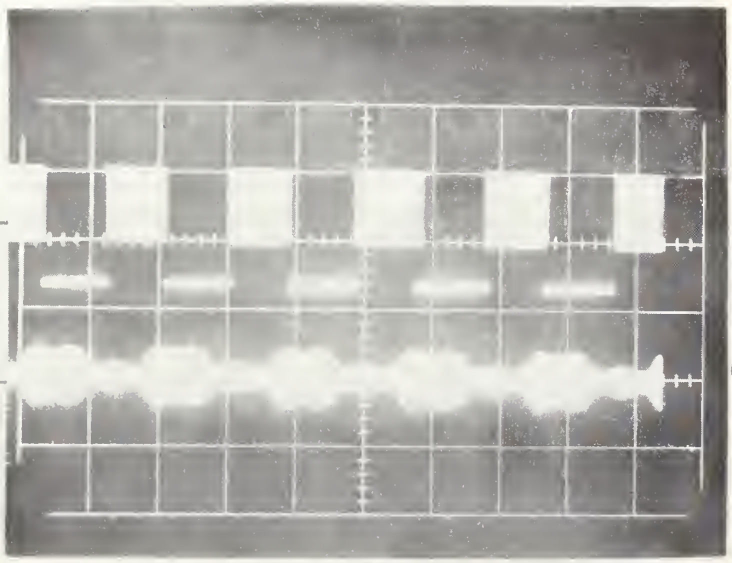
2.0 ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
3	C	250	2	1.0	67	0.010	-40	+40	-80

Media: Steel - Air - Steel

XMT: 2

RCV: B



1.0 V

Test No. 19

0.05 V

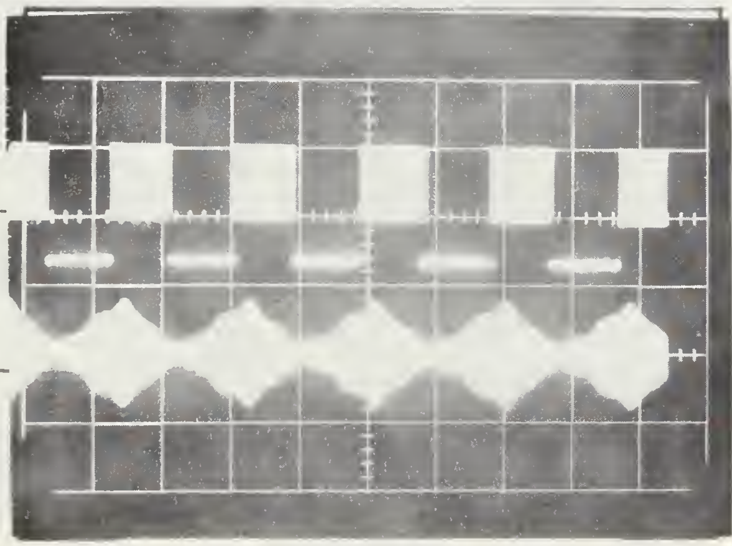
2.0 ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
2	B	250	2	1.0	61	0.020	-34	+40	-74

Media: Steel - Air

XMT: 1

RCV: A



1.0 V

Test No. 20

0.05 V

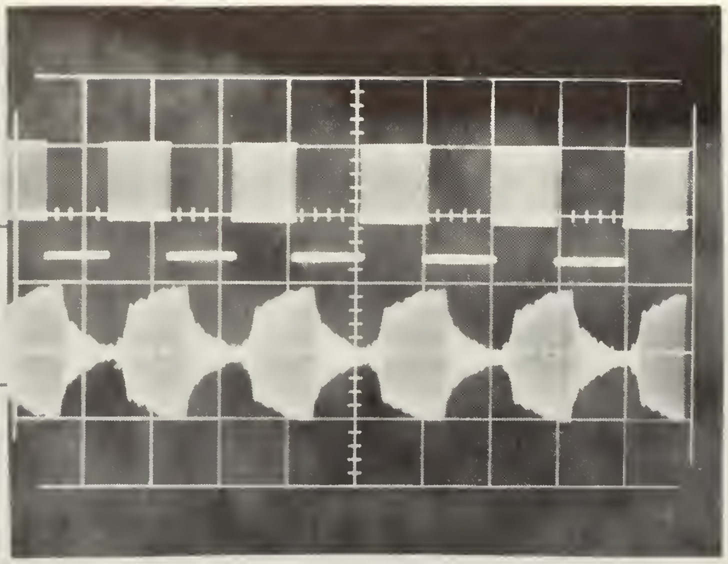
2.0 ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
1	A	250	2	1.0	66	0.040	-28	+40	-68

Media: Air

XMT: 1

RCV: B



1.0 V

Test No. 21

1.0 V

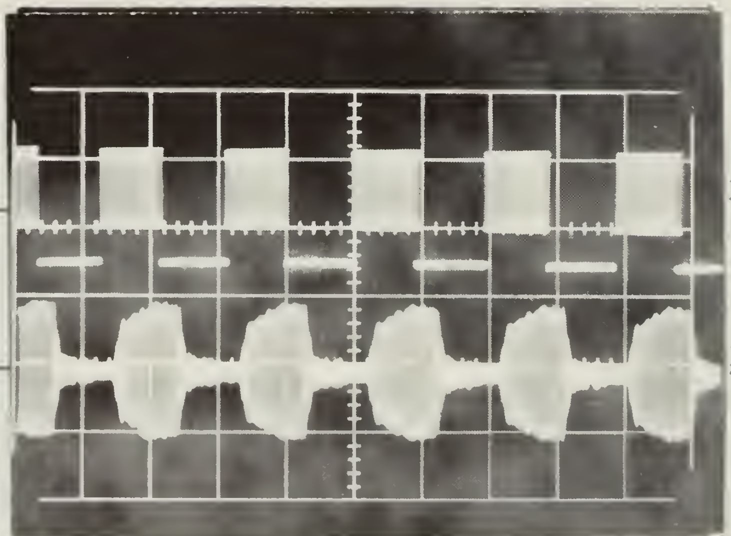
2.0 ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
1	B	250	2	1.0	235	1.000	0	+38	-38

Media: Water

XMT: B

RCV: 1



1.0 V

Test No. 22

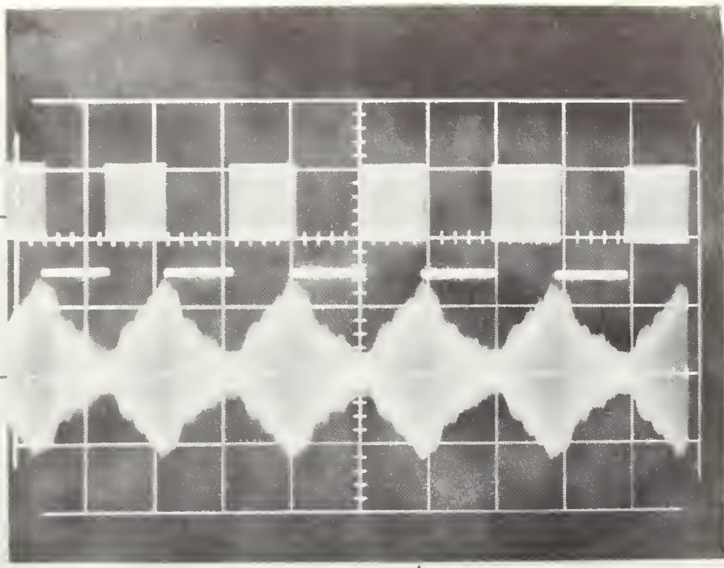
1.0 V

2.0 ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
B	1	250	2	1.0	235	1.000	0	+38	-38

Media: Water

XMT: 1



1.0 V

Test No. 23

RCV: C

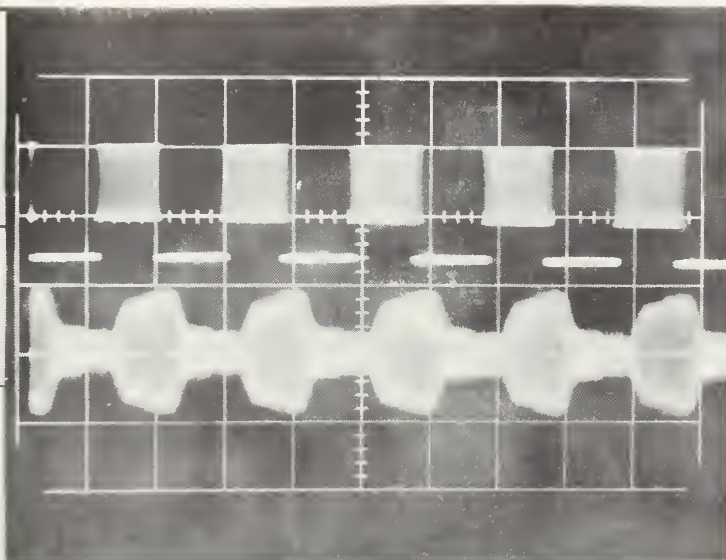
0.2 V

2.0 ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
1	C	250	2	1.0	235	0.280	-11	+38	-49

Media: Water - Steel

XMT: C



1.0 V

Test No. 24

RCV: 1

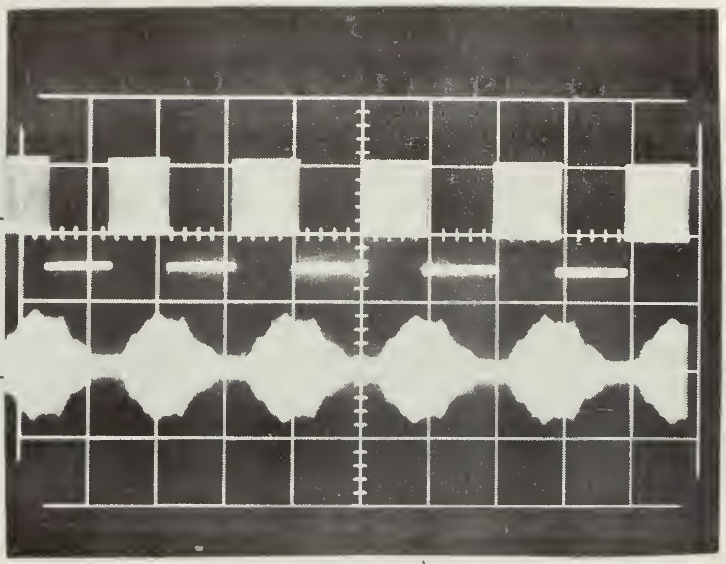
0.2 V

2.0 ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
C	1	250	2	1.0	250	0.180	-15	+37	-52

Media: Steel - water

XMT: 1



1.0 V

Test No. 25

RCV: 2

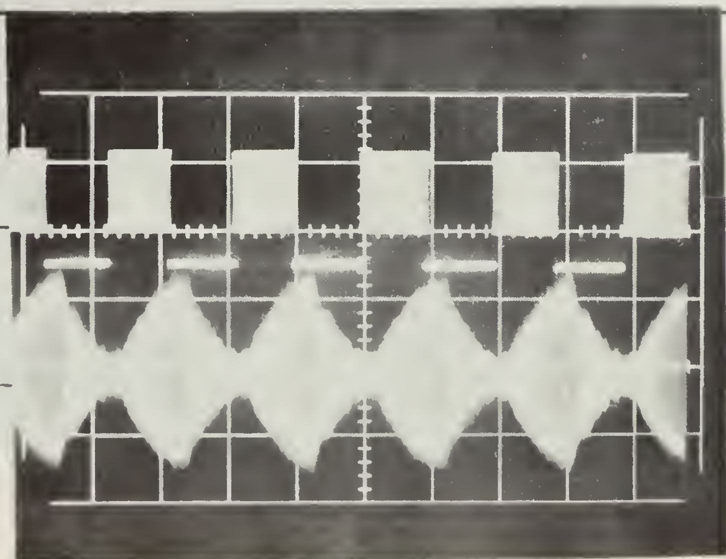
0.2 V

2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
1	2	250	2	1.0	235	0.160	-16	+38	-54

Media: Water - Steel

XMT: 2



1.0 V

Test No. 26

RCV: 1

0.1 V

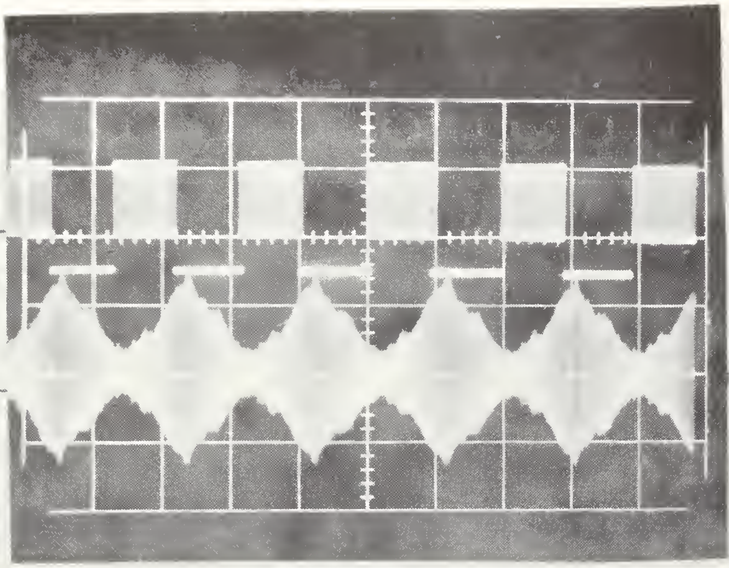
2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
2	1	250	2	1.0	238	0.140	-17	+38	-55

Media: Steel - Water

XMT: 1

RCV: 3



1.0 V

Test No. 27

0.2 V

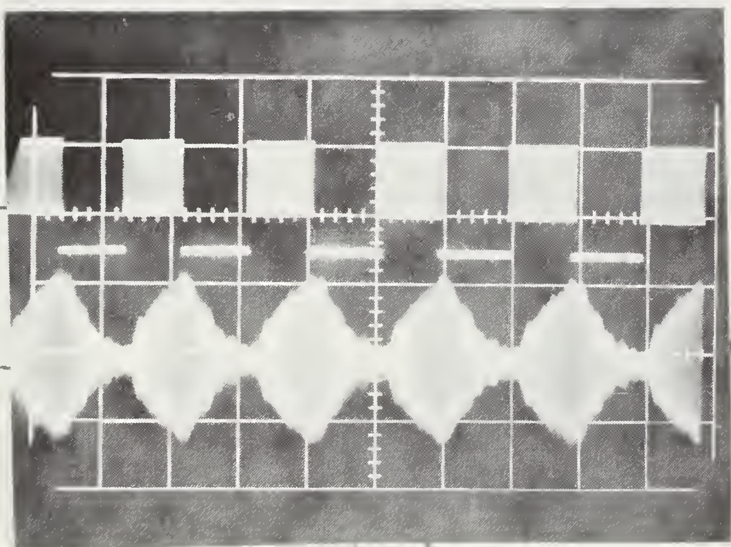
2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
1	3	250	2	1.0	225	0.250	-12	+38	-50

Media: Water - Steel

XMT: 3

RCV: 1



1.0 V

Test No. 28

0.2 V

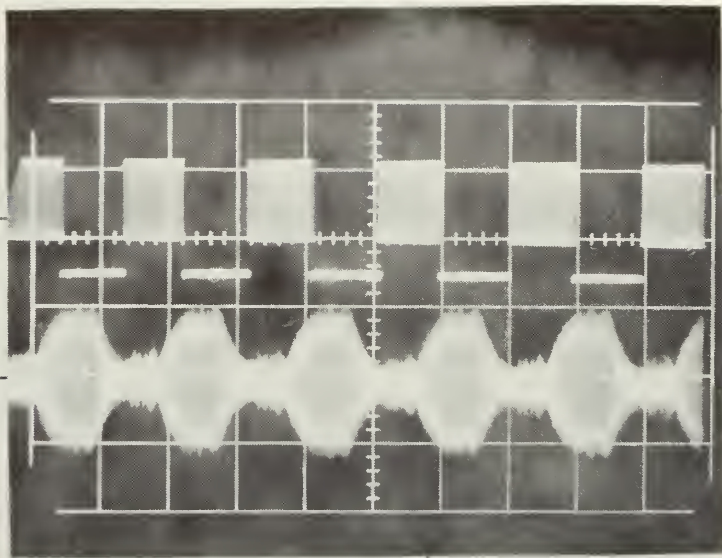
2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
3	1	250	2	1.0	240	0.225	-13	+38	-51

Media: Steel - Water

XMT: 2

RCV: A



1.0 V

Test No. 29

0.1 V

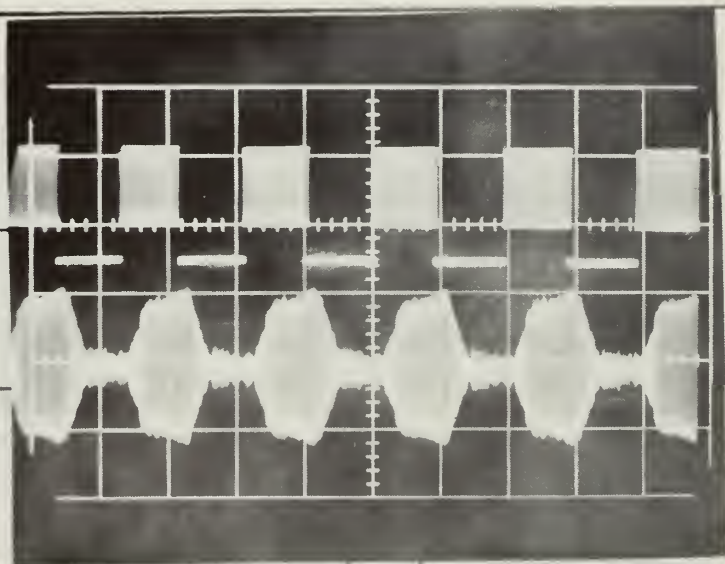
2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
2	A	250	2	1.0	230	0.100	-20	+38	-58

Media: Steel - Water

XMT: A

RCV: 2



1.0 V

Test No. 30

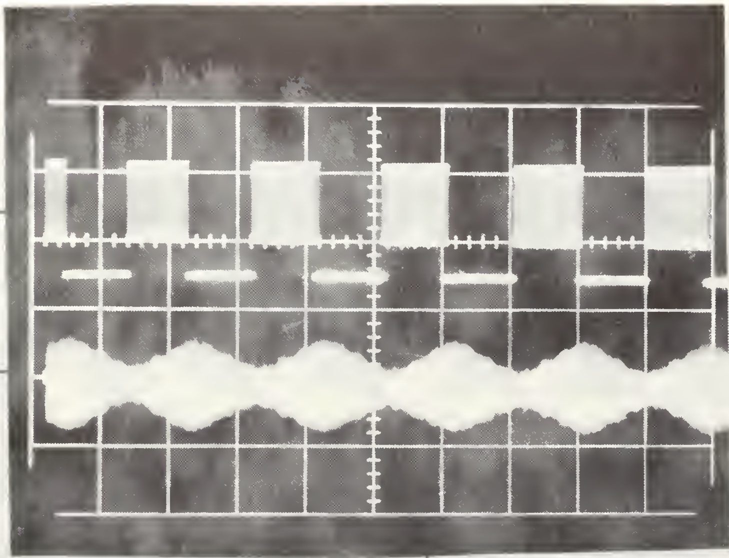
0.1 V

2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
2	2	250	2	1.0	235	0.100	-20	+38	-58

Media: Water - Steel

XMT: 2



1.0 V

Test No. 31

RCV: C

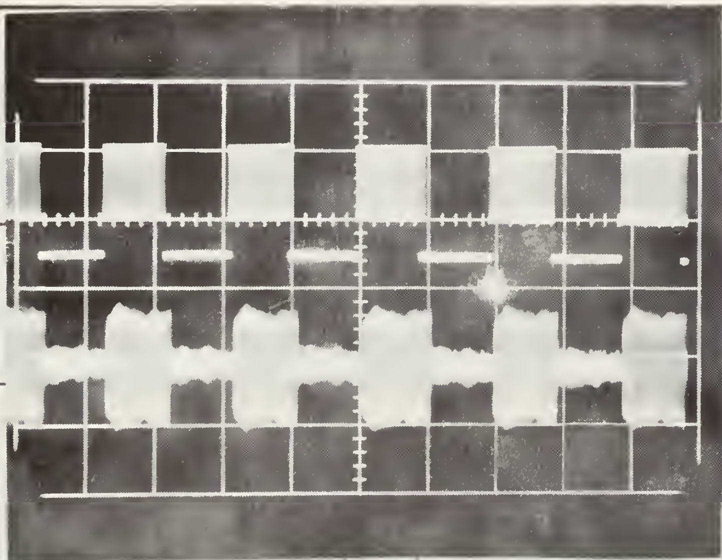
0.05 V

2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
2	C	250	2	1.0	235	0.035	-29	+38	-67

Media: Steel - Water - Steel

XMT: C



1.0 V

Test No. 32

RCV: 2

0.05 V

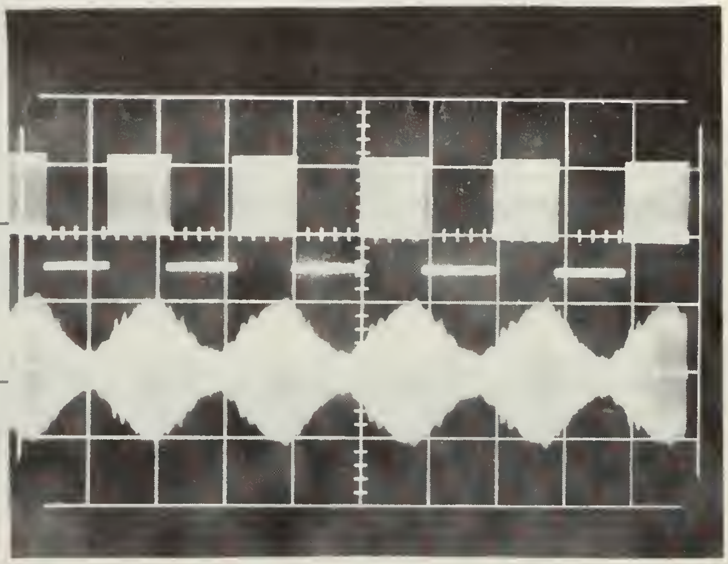
2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
C	2	250	2	1.0	250	0.045	-27	+37	-64

Media: Steel - Water - Steel

XMT: 2

RCV: 3



1.0 V

Test No. 33

0.05 V

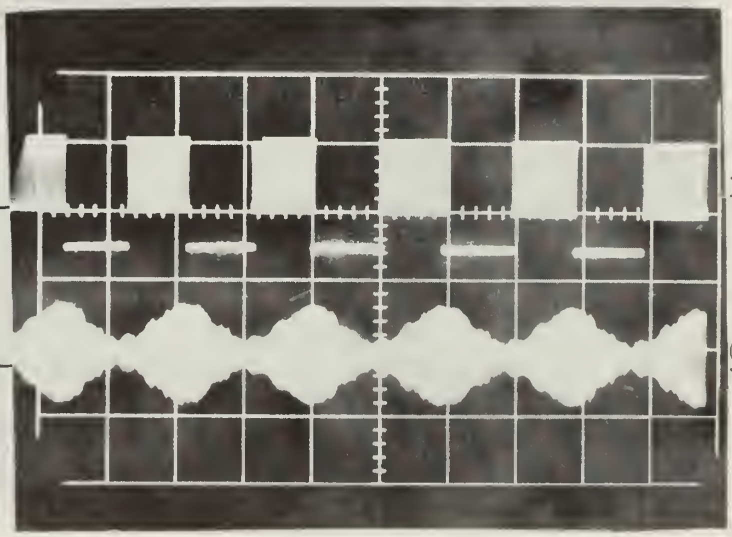
2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
2	3	250	2	1.0	240	0.050	-26	+38	-64

Media: Steel - (Water) - Steel

XMT: 3

RCV: 2



1.0 V

Test No. 34

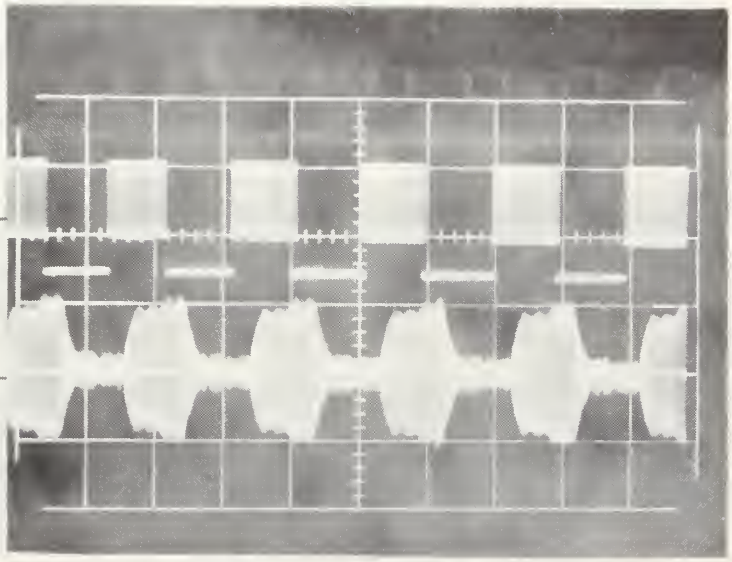
0.1 V

2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
3	2	250	2	1.0	250	0.063	-24	+37	-61

Media: Steel - (Water) - Steel

XMT: 3



RCV: B

1.0 V

Test No. 35

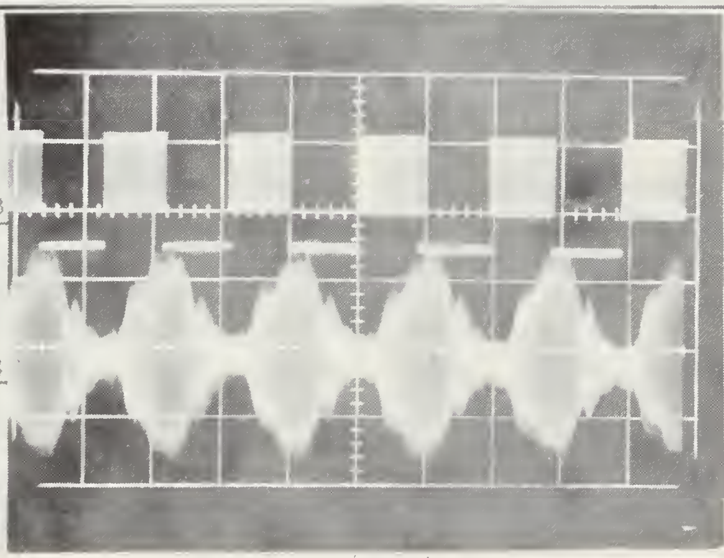
0.2 V

2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
3	B	250	2	1.0	[illegible]	[illegible]	-14	+38	-52

Media: Steel - Water

XMT: B



RCV: 3

1.0 V

Test No. 36

0.2 V

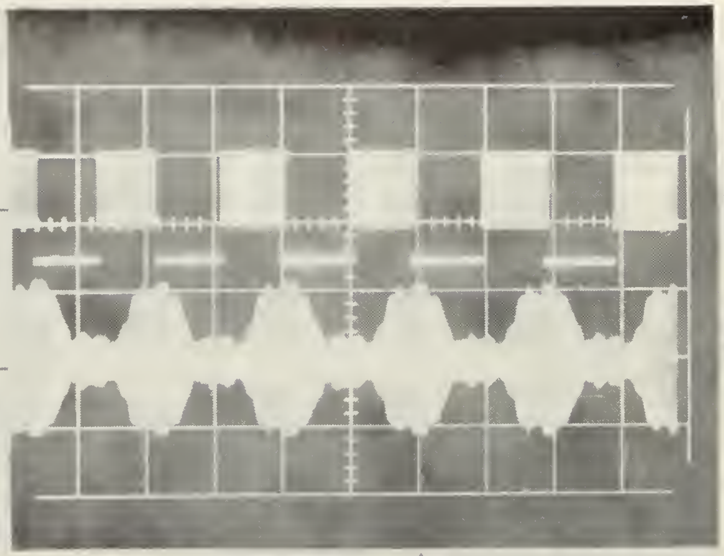
2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
B	3	250	2	1.0	265	0.280	-11	+37	-48

Media: Water - Steel

XMT: 3

RCV: A



1.0 V

Test No. 37

0.2 V

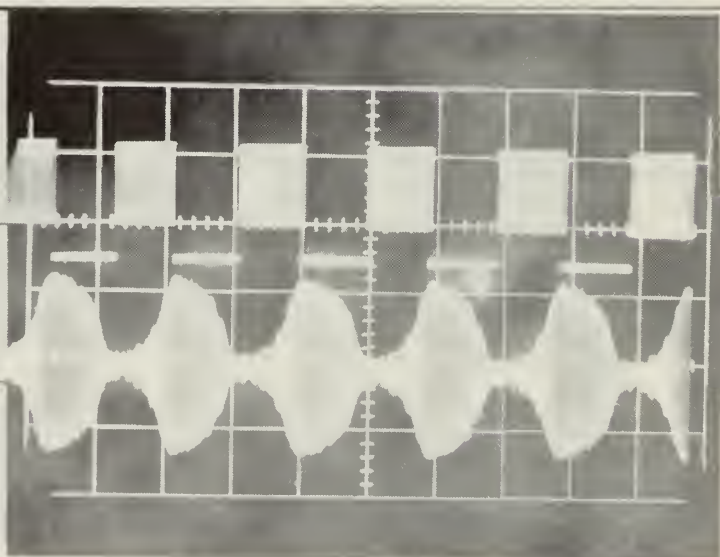
2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
3	A	250	2	1.0	225	0.200	-14	+38	-52

Media: Steel - Water

XMT: A

RCV: 3



1.0 V

Test No. 38

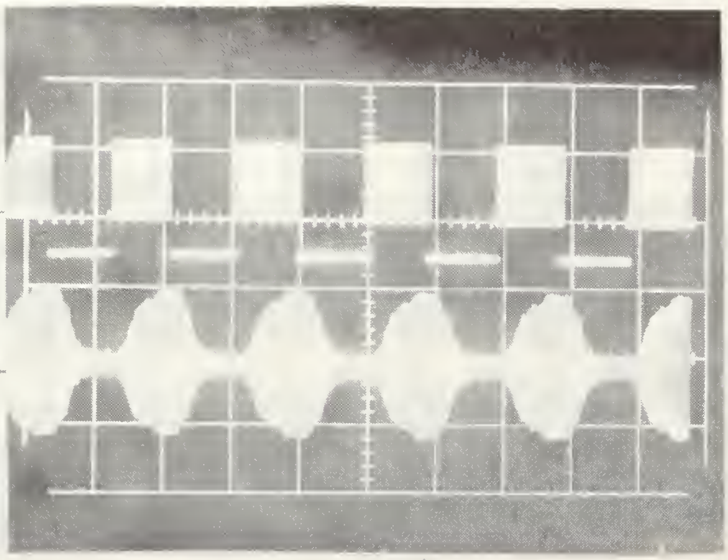
0.2 V

2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
A	3	250	2	1.0	265	0.250	-12	+47	-59

Media: Water - Steel

XMT: A



1.0 V

Test No. [illegible]

RCV: B

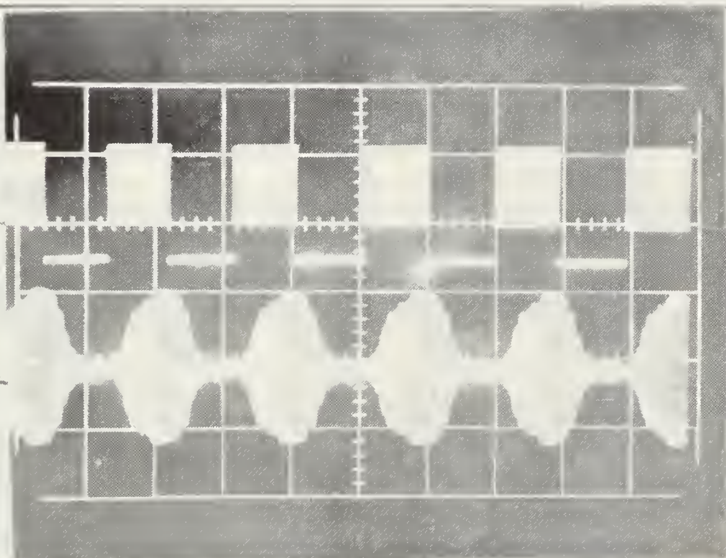
[illegible] V

2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
A	B	250	2	1.0	235	1.[illegible]	[illegible]	-38	[illegible]

Media: Water

XMT: B



1.0 V

Test No. 4[illegible]

RCV: A

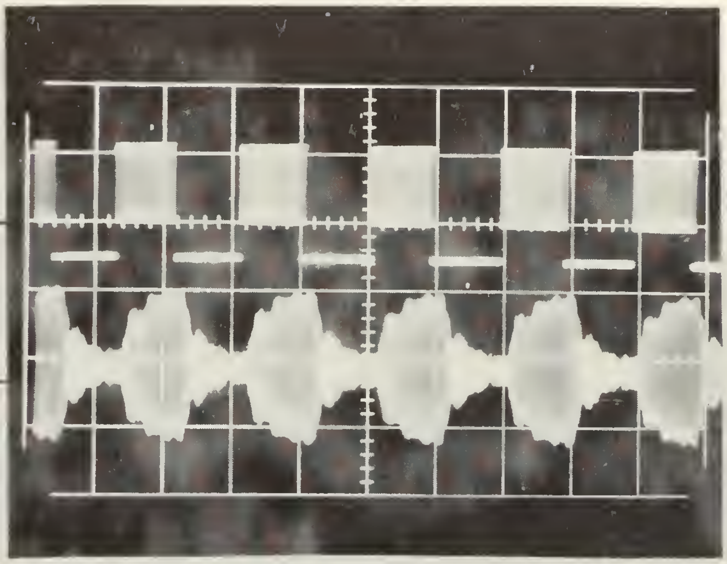
[illegible].0 V

2.[illegible] ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
B	A	250	2	1.0	235	1.[illegible]	0	[illegible]	[illegible]

Media: [illegible]

XMT: A



RCV: C

1.0 V

Test No. 41

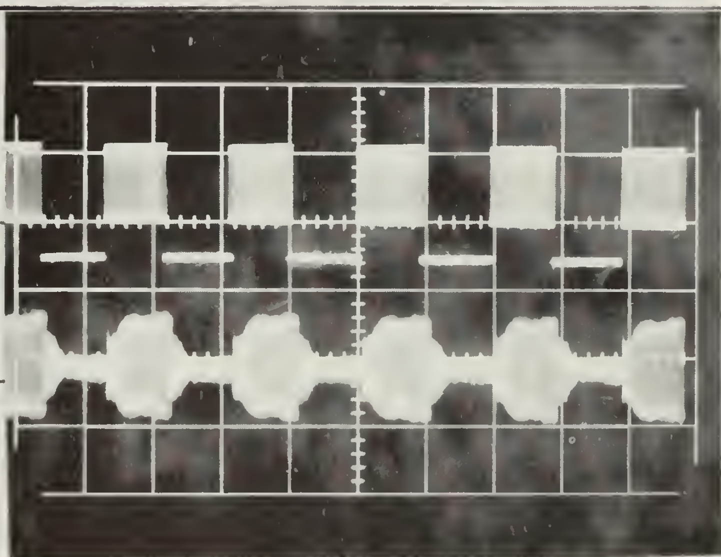
0.2 V

2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
A	C	250	2	1.0	235	0.200	-14	+38	-52

Media: Water - Steel

XMT: C



RCV: A

1.0 V

Test No. 42

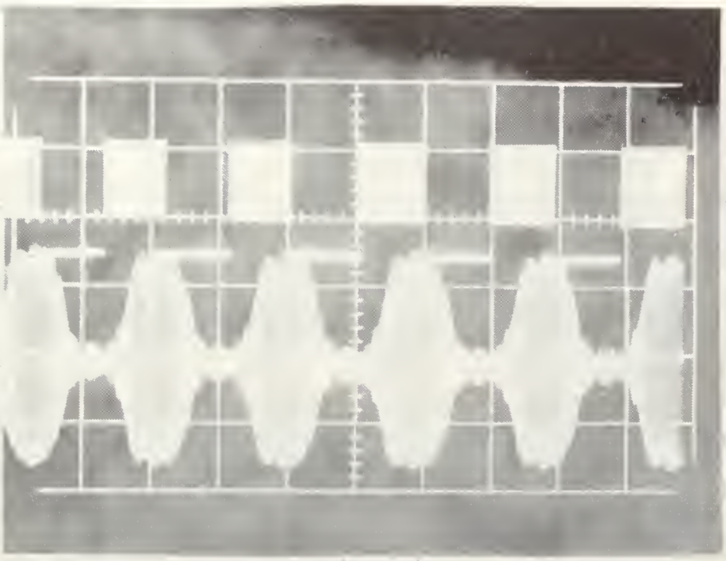
0.5 V

2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
C	A	250	2	1.0	230	0.400	-8	+38	-46

Media: Steel - Water

XMT: 1.0 V



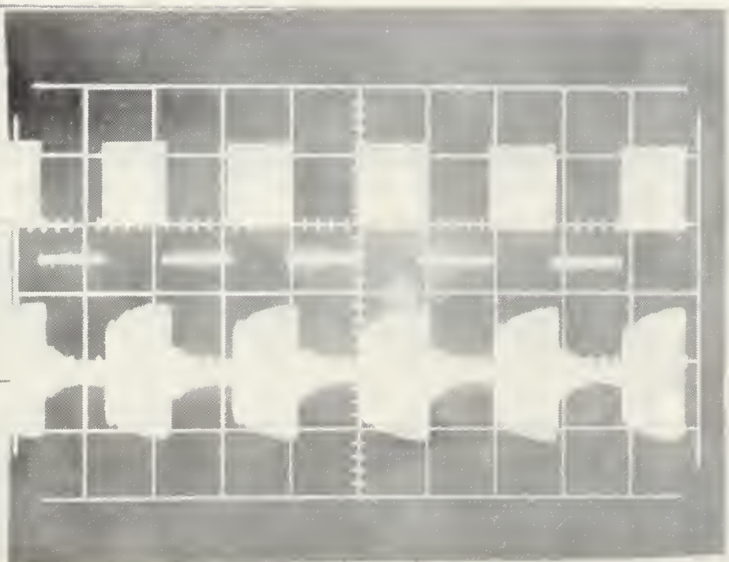
Test No.

RCV:

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Media: [illegible]

XMT: 1.0 V



Test No.

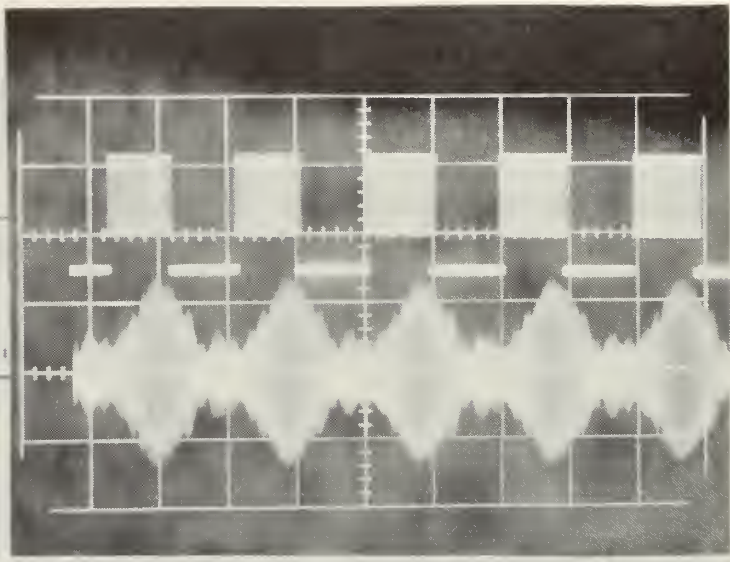
RCV:

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
C	[illegible]	[illegible]	2	[illegible]	[illegible]	[illegible]	-6	[illegible]	[illegible]

Media: Steel - Water

XMT: 1

RCV: 2'



1.0 V

Test No. 45

0.2V

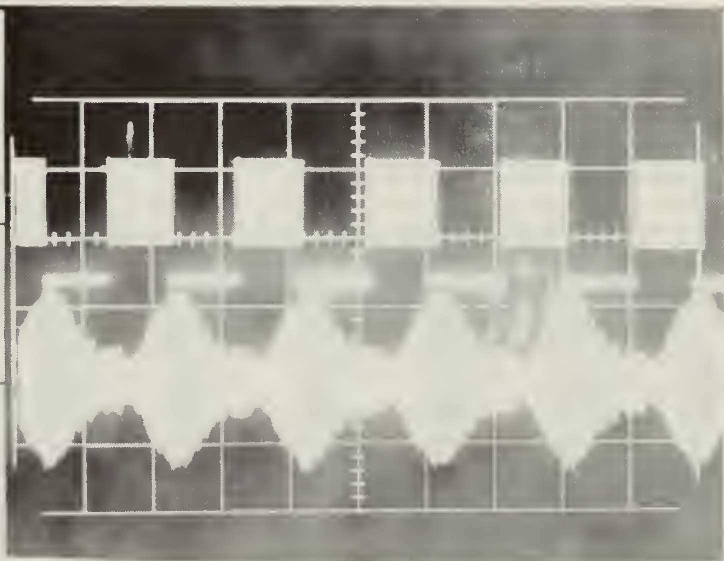
2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
1	2'	250	2	1.0	215	0.250	-12	+33	-50

Media: Water - Note: 2' located in outer end plate at a distance of 91 cm and penetrates plate.

XMT: 2'

RCV: 1



1.0 V

Test No. 46

[illegible]

2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
2'	1	250	2	1.0	230	0.125	-18	+38	-56

Media: Steel - Water - Note: 2' located in outer end plate at a distance of 91 cm and penetrates plate.

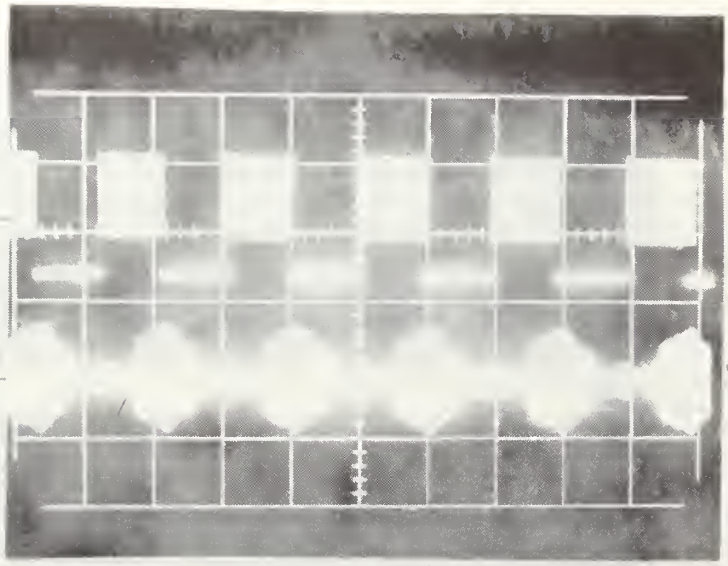
XMT: A

1.0 V

Test No. 47

RCV: 2'

0.5V



2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
A	2'	250	2	1.0	215	0.400	-8	+38	-46

Media: Water - Note: 2' located in outer end plate at a distance of [illegible] cm and penetrates plate.

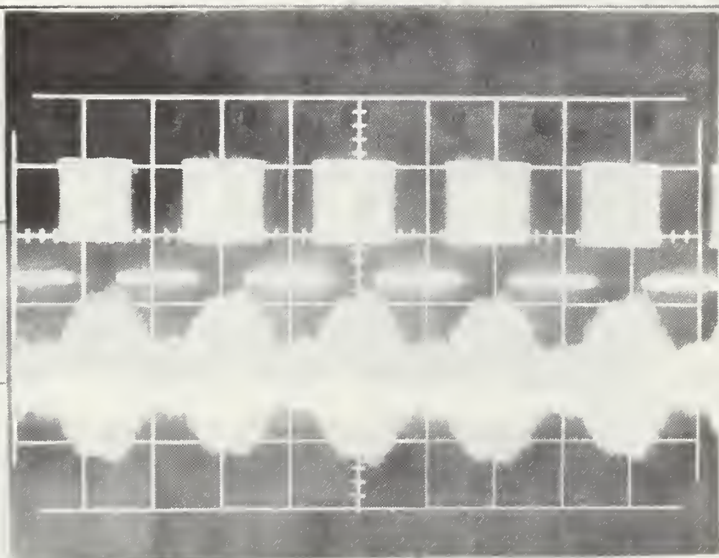
XMT: C

1.0 V

Test No. 48

RCV: 2'

0.1V



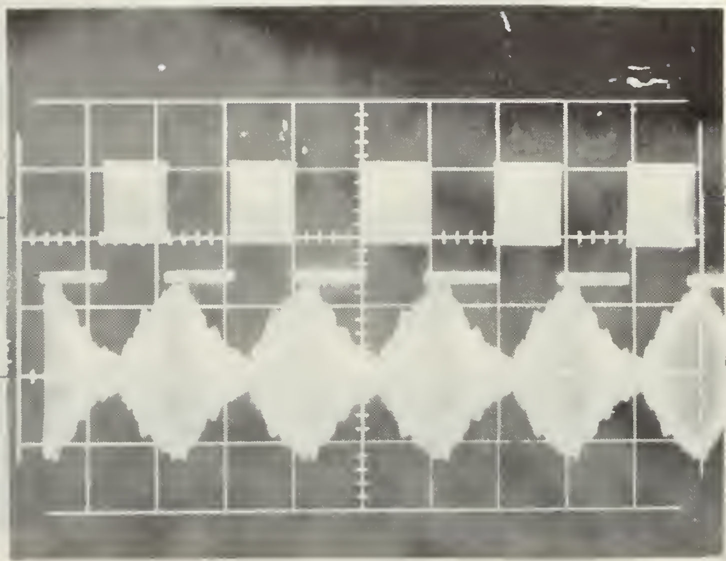
2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
C	2'	230	2	1.0	220	0.100	-20	+38	-58

Media: Steel - Water - Note: 2' located in outer end plate at a distance of 91 cm and penetrates plate.

XMT: 1

RCV: 2"



1.0 V

Test No. 49

0.05V

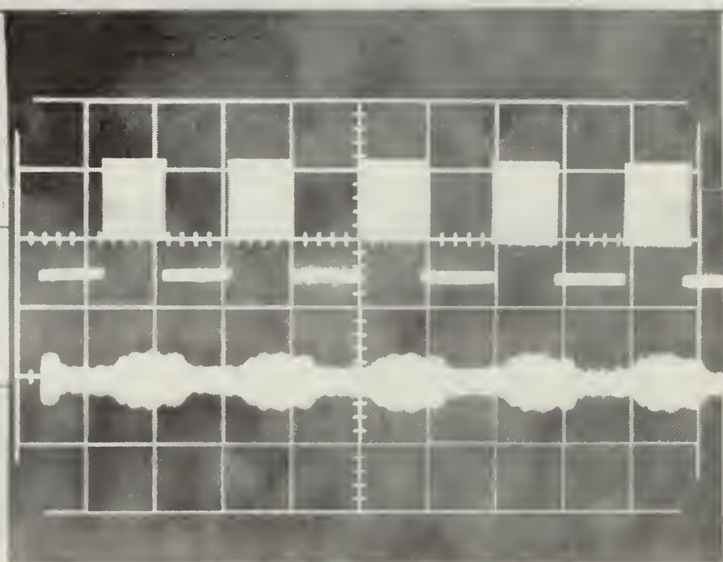
2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
1	2"	[illegible]	2	1.	[illegible]	0.056	-25	+38	-63

Media: Water - Steel - Water. 2" located in outer closure cap at a distance of 62 cm and does not penetrate cap.

XMT: 2"

RCV: 3



1.0 V

Test No. 50

0.05V

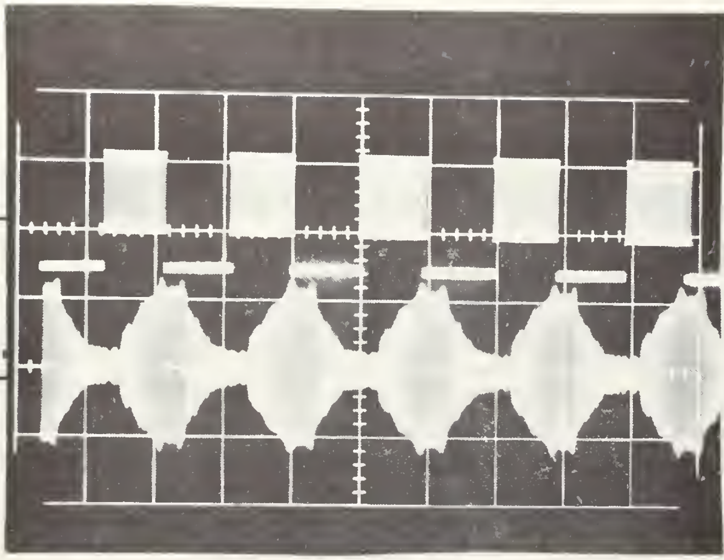
2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
2"	[illegible]	350	2	1.0	147	0.025	-32	+37	-69

Media: Steel - (Water) - Steel - Note: 2" located in outer closure cap at a distance of 62 cm and does not penetrate cap.

XMT: A

RCV: 2"



1.0 V

Test No. 51

0.05V

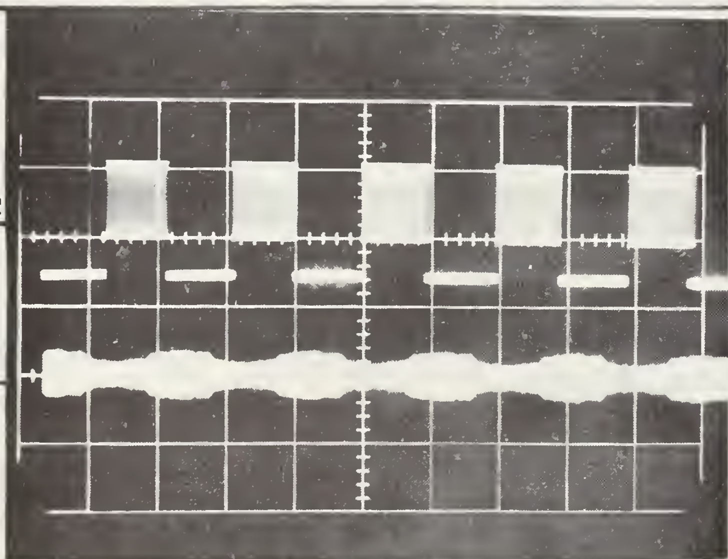
2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
A	2"	250	2	1.0	252	0.063	-24	+37	-61

Media: Water - Steel - Note: 2" located in outer closure cap at a distance of 62 cm and does not penetrate cap.

XMT: C

RCV: 2"



1.0 V

Test No. 52

0.05V

2ms

Mode XMT	Mode RCV	PRR pps	PD ms	Vpi V	Frq kHz	Vpo V	Vpo/Vpi dB	Ampl dB	Attn dB
C	2"	250	2	1.0	250	0.016	-36	+37	-73

Media: Steel - Water - Steel
Note: 2" located in outer closure cap at a distance of 62 cm and does not penetrate cap.

LIST OF REFERENCES

1. CRAWFORD, Alan E., Ultrasonic Engineering -- With Particular Reference to High-Power Applications, Butterworth Scientific Publications, London, 1955.

The introductory chapter contained one of the best explanations of ultrasonic acoustic wave propagation. The final chapter (pp. 306-337) presented many interesting examples of the employment of ultrasonic devices. Of particular interest were a portable ultrasonic device used for the measurement of the thickness of solid materials (p.315) and another portable ultrasonic device with separate probe-transducers for the detection of flaws and discontinuities in solid materials.

2. KINSLER, Lawrence E. and FREY, Austin R., Fundamentals of Acoustics, 2nd Ed., John Wiley & Sons, New York, 1962.

This was the basic reference used to enhance an understanding of the principles and concepts involved in coupling the transmission through the media by acoustical means. Specifically, the following chapters were most helpful: Chapters 5 and 7 for the theory of propagation of acoustic plane and spherical waves; Chapter 6 for insight into the phenomena of transmission by acoustical means and the parameters that must be considered for a mathematical formulation; Chapter 9 for an understanding of attenuation, dispersion, and absorption of sound waves in fluids; and Chapter 12 for the principles and concepts used in the design and operation of ultrasonic transducers.

3. RAEMER, Harold R., Statistical Communications -- Theory and Application, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1969.

This is one of the latest references and could be used for the development of signal processing and coding schemes that would be necessary for an actual working system. Employment of the technique suggested by the investigation would require the information to be coded and/or modulated in serial form upon the carrier.

4. REDWOOD, Martin, Mechanical Waveguides -- The Propagation of Acoustic and Ultrasonic Waves in Fluids and Solids with Boundaries, Pergamon Press Ltd., Oxford, 1960.

If the continuation of research for the employment of this technique was the development and formulation of a mathematical model for any given system, then this would be a good reference with which to begin. A computer program could be written that would allow system simulation with varying parameters while outputting the parameters for the devices to be employed.

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13. ABSTRACT

Ultrasonic transducers were used to couple the transmission of continuous-wave and pulse-modulated signals across relatively short paths of less than one meter through media of various densities. The experimental model used consisted of two concentric, cylindrical, stainless-steel tanks, one inside the other, with the area between them filled with either water or air. The investigation showed the feasibility of transmitting usable data to and from a unit which was isolated from a data source, i.e., from outside the outer tank to inside the inner tank, and vice versa, without physically penetrating the walls of either tank. An application hypothesis for a Submarine Launched Weapon System is presented as an example of employment of this technique since the weapon vehicle is relatively isolated from the fire-control system and since the elimination of cabling between the launcher and the weapon should enhance system performance.

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KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Feasibility Study						
Acoustic Coupling						
Ultrasonic Transducer						
Data Transmission						
Various Media						
Submarine Launched Weapon						

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